Physics Beyond Colliders

The Search for Feebly-Interacting Particles and the Physics Beyond Colliders activity at CERN

https://pbc.web.cern.ch/

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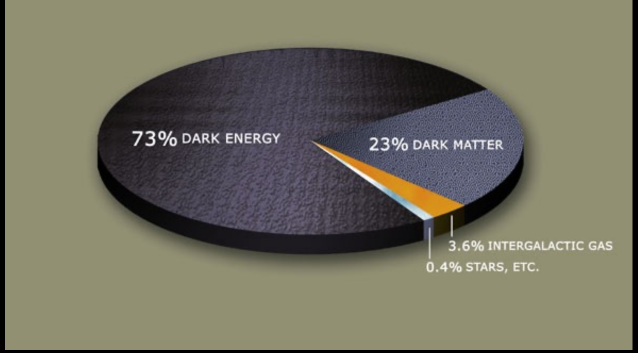
LNF-INFN

Cosmic Wispers, kick-off meeting, LNF, February 2023

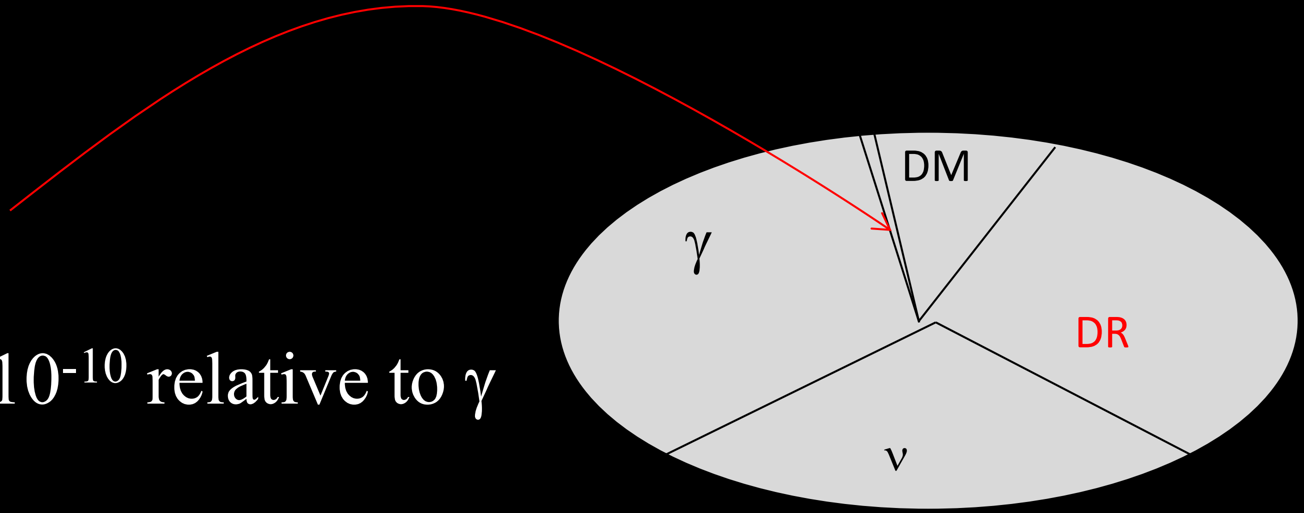


Evidence for New Physics

Atoms

In Energy chart they are 4%.

In number density chart ~ 5×10^{-10} relative to γ



We have no idea about DM number densities. (WIMPs ~ 10^{-8} cm^{-3}; axions ~ 10^{9} cm^{-3}. Dark Radiation, Dark Forces – Who knows!).

Lack of precise knowledge about nature of dark matter leaves a lot of room for existence of dark radiation, and dark forces – dark sector or feebly interacting particles, in general.

Preamble

October 2019

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.”

Physics Beyond Colliders

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 scales (as data seem to suggest)]

Fully complementary to high-energy searches.
Naturally long-lived.

New IR degrees of freedom = light (e.g. sub-GeV) BSM states

Typical BSM model-independent approach is to include all possible BSM operators once very heavy new physics is integrated out:

$L_{SM+BSM} = - m_H^2\, (H^+_{SM} H_{SM})$ + all dim 4 terms (A_{SM}, y_{SM}, H_{SM}) +
(W.coeff. $/L^2$) × Dim 6 etc (A_{SM}, y_{SM}, H_{SM}) + …
all lowest dimension portals $(A_{SM}, y_{SM}, H, A_{DS}, y_{DS}, H_{DS})$ × portal couplings
+ dark sector interactions (A_{DS}, y_{DS}, H_{DS})

SM = Standard Model
DS – Dark Sector

Golden rule of any EFT approach: first look at low-dim operators !

Physics Beyond Colliders

The Portal Framework

Expand the SM with the minimal set of operators of lowest dimension gauge-invariant and renormalizable (all but the pseudo-scalar). This guarantees that the theoretical structure of the SM is preserved and any NP is just a simple (natural?) extension of what we already know..

PBC-BSM Report, 1901.09966, J. Phys. G47 (2020) 1

Portal	Coupling
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$
Axion, a	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu} \tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a} \overline{\psi} \gamma^\mu \gamma^5 \psi$
Sterile Neutrino, N	$y_N L H N$

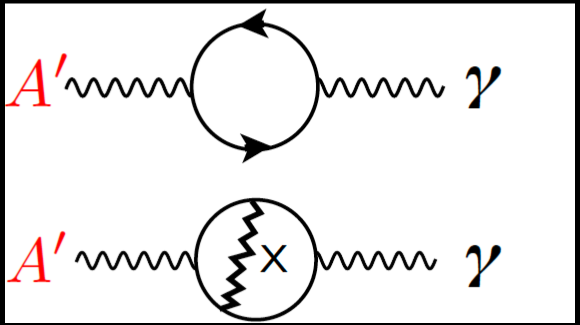
The full set of allowed renormalizable interactions for dark sector with SM, consistent with SM Gauge invariance (plus one notable generalization)

They are representative of broad classes of models:
Each may predict distinct texture of New Physics interactions

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).

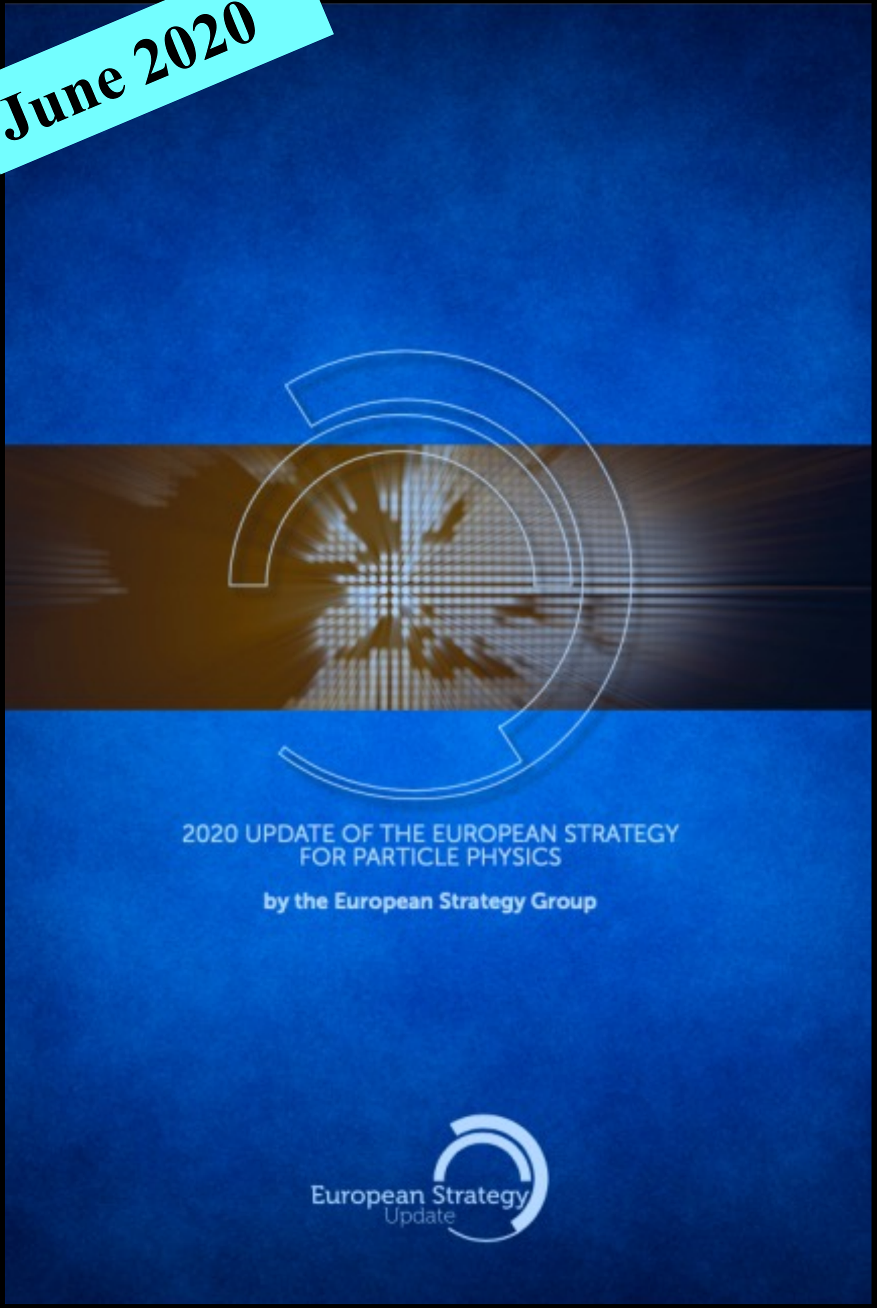


- Some portal interactions are suppressed by large value of the cut off scale (eg: axion portal)

- Small couplings in general can motivate small masses, naturally (analogous to m_{proton}, $m_{electron}$ << m_{weak} in Standard Model)

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

June 2020

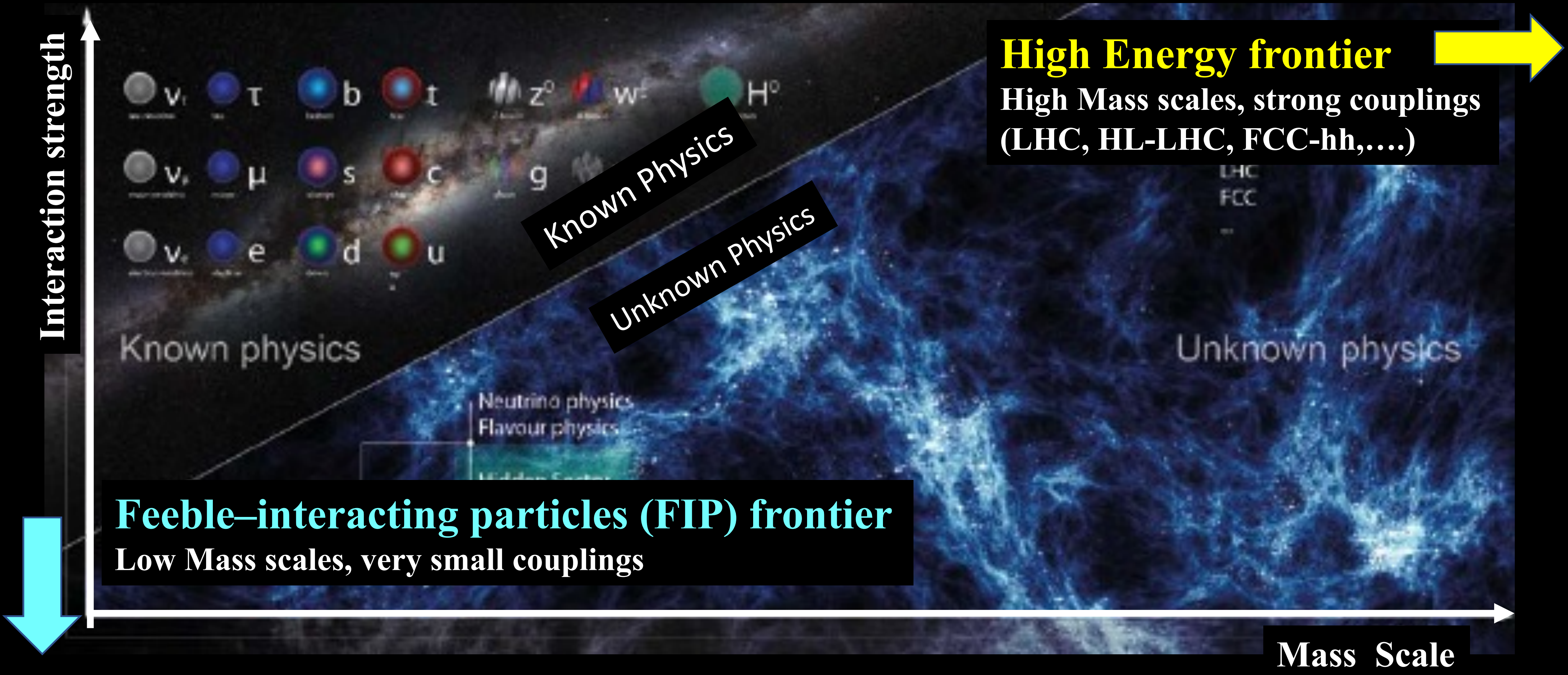


ESPP Recommendations

- *"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.*

https://cds.cern.ch/record/2721370/files/CERN-ESU-015 2020%20Update%20European%20Strategy.pdf

FIPs: a change in perspective….



What FIPs can provide us?

1) Thermal DM candidates that extend the WIMP paradigm.
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,…..

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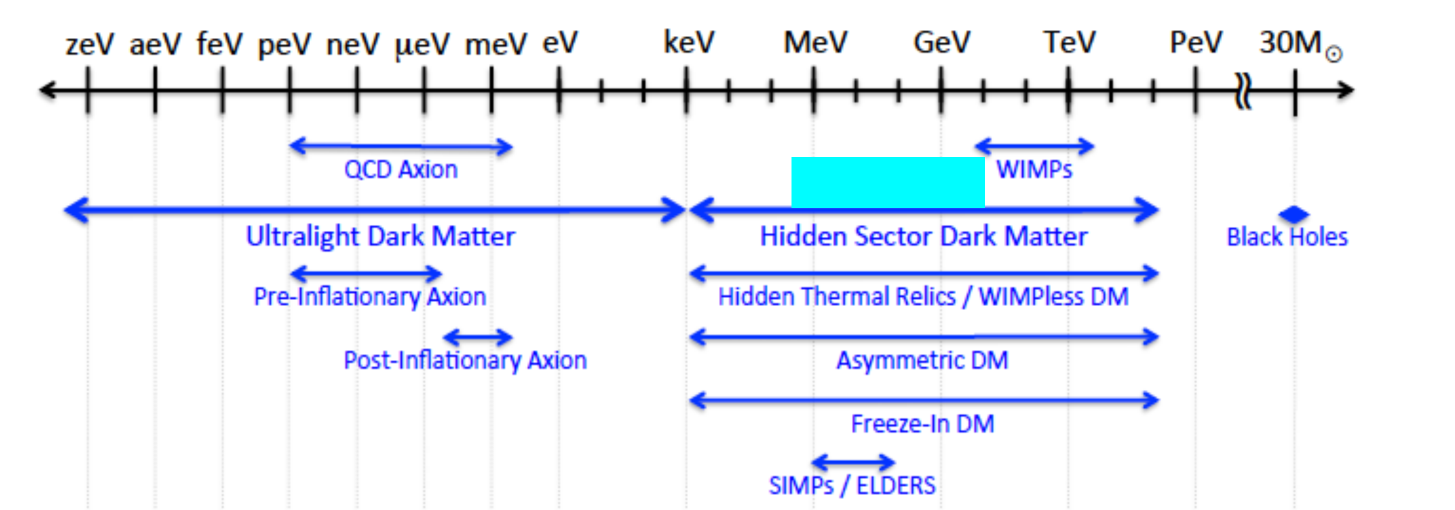
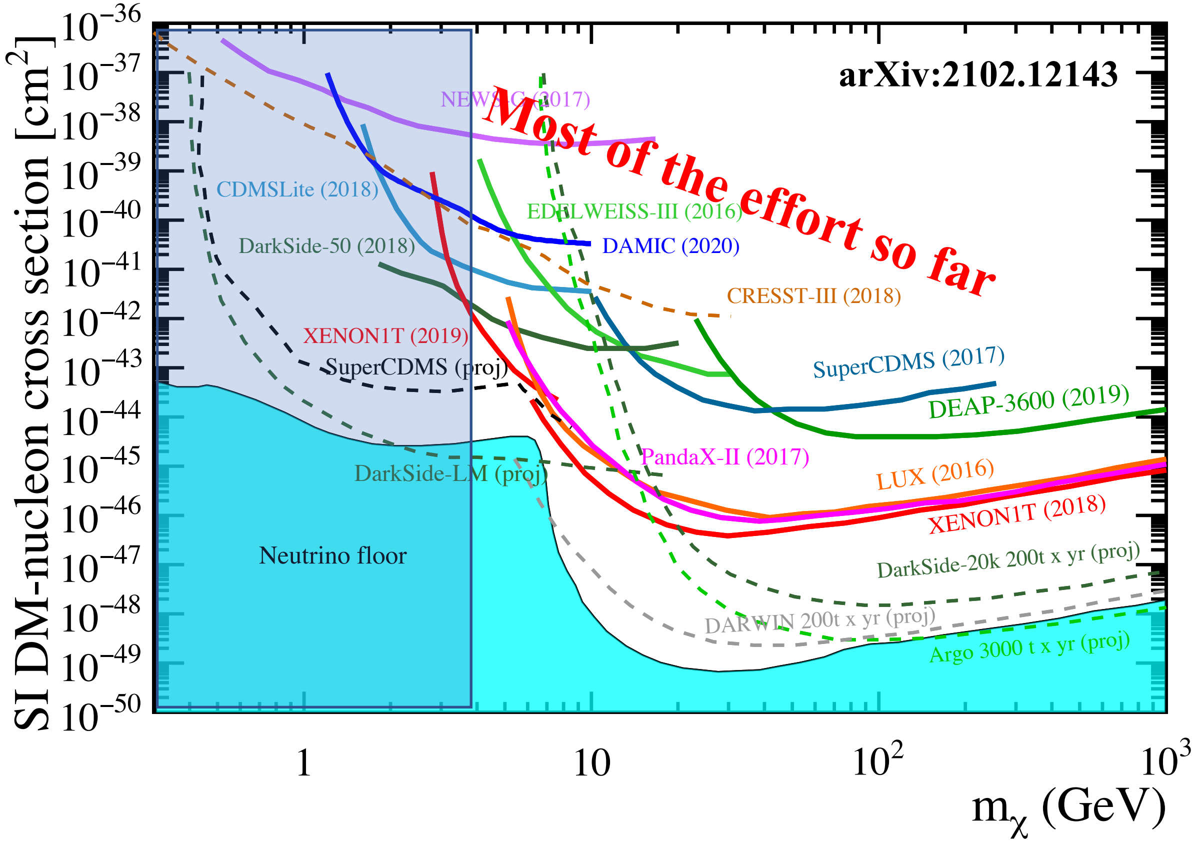
DM available mass range
~ 80 orders of magnitude..



Cosmic Visions, arXiv:1707.04591

Direct Detection DM searches below a few GeV: A vibrant field.

DM in the MeV-GeV range: a blooming field →



DM direct detection experiments are pushing the exploration down to the neutrino floor in the MeV-GeV range

MeV-GeV range is accessible also by accelerator-based experiments.

Light DM with thermal origin with a new light Vector Mediator

(with new forces/interactions the Lee-Weinberg bound can be evaded)

Accelerator-based experiments

Production of DM at accelerators
(via SM (electron/proton/..) particles)

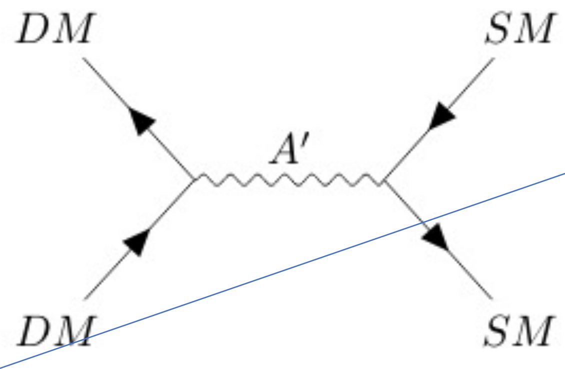
$$< \sigma v > \sim \alpha_D \varepsilon^2 \alpha \times \frac{m_{\rm DM}^2}{m_{A'}^4} \times m_{\rm DM}^2 \times \frac{1}{m_{\rm DM}^2}$$

y variable

DM Direct detection experiments

DM scattering with e/protons

$$\sigma(DMe^- \to DMe^-) \sim 3.7 \cdot 10^{-27}\text{cm}^2 \times \left(\frac{10\ \text{MeV}}{m_{\rm DM}}\right)^4 \times y$$



Astroparticle, cosmology

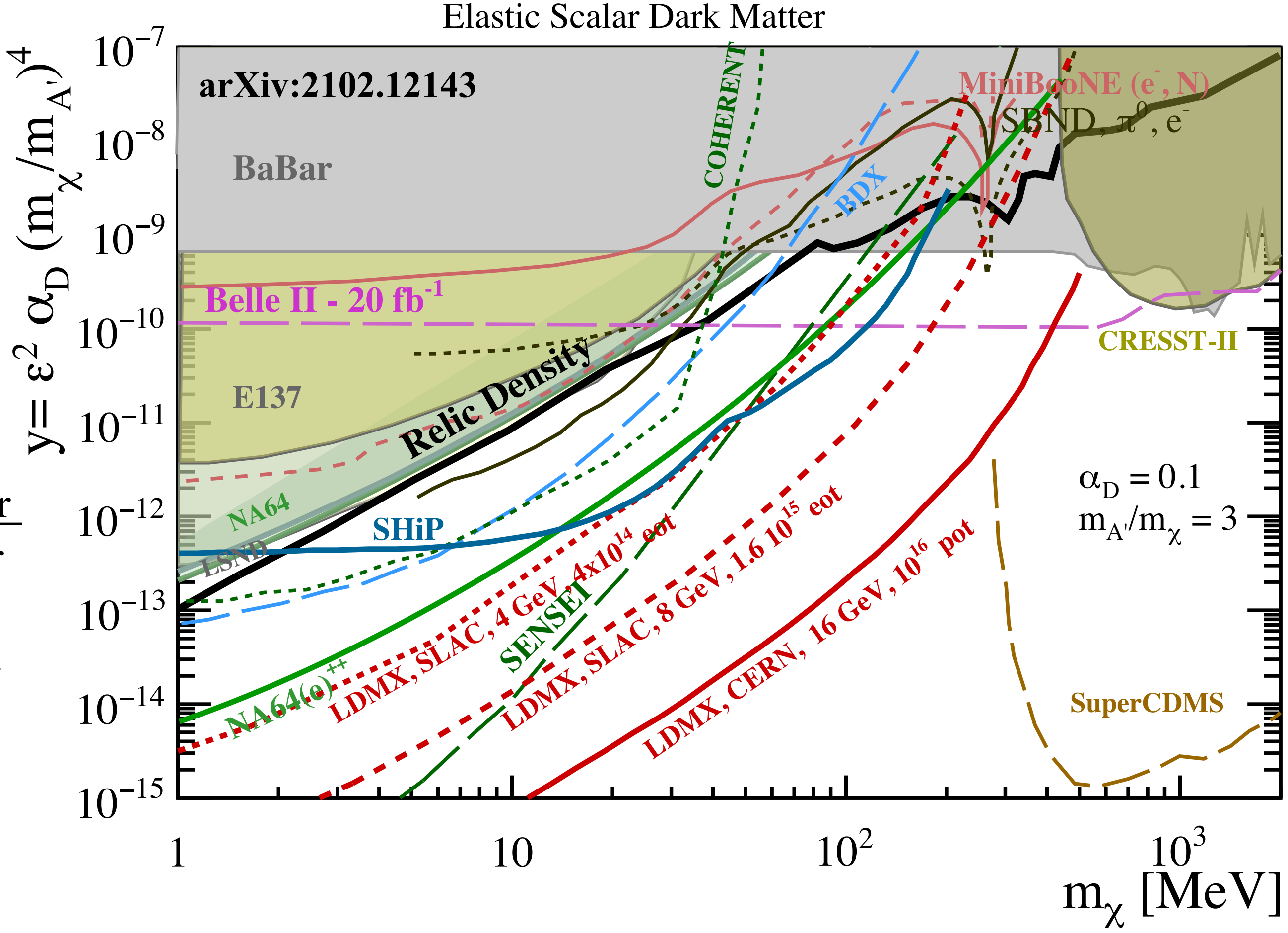
Direct DM annihilation
(main process to get the thermal relic abundance)

$$\Omega_{\rm DM} h^2 \sim \frac{10^9\ \text{GeV}^{-1}}{M_{\rm pl}} \frac{1}{\langle \sigma v \rangle}$$

Light DM with thermal origin with a new light Vector Mediator

(with new forces/interactions the Lee-Weinberg bound can be evaded)

If the DM is Elastic Scalar the annihilation via vector mediator is in p-wave and the CMB bound is evaded



PBC projects:

NA64^{++}(e), NA64(μ), SHiP,…

Worldwide landscape:

- Accelerator-based:
  Belle-II, BDX, SBND, MiniBooNE, LDMX,…
- Direct Detection:
  CRESST-II, SuperCDMS, SENSEI..

Major Labs involved:

CERN, KEK, JLAB, FNAL, SLAC, SNOLAB, Gran Sasso,…

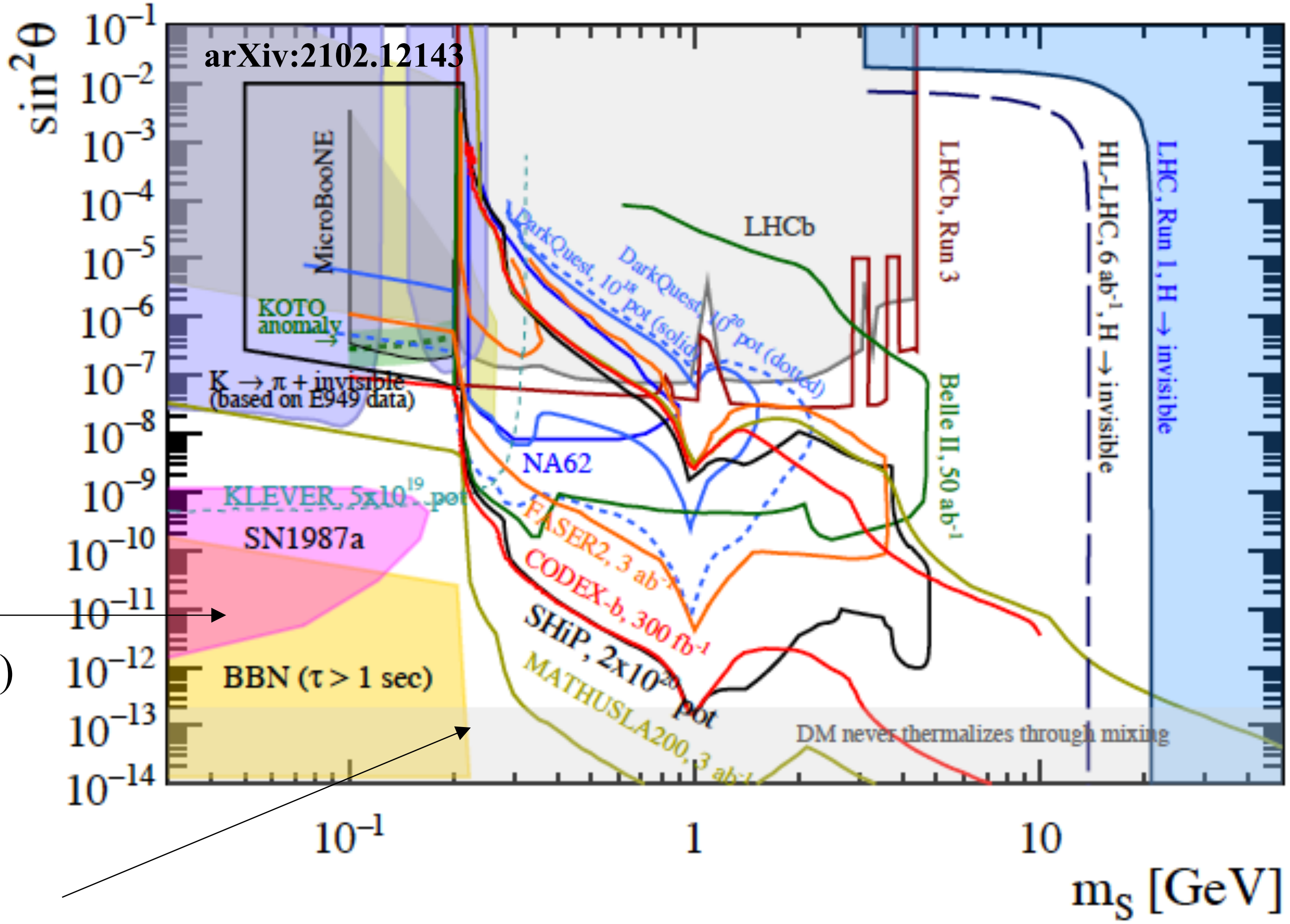
Within this model accelerator-based results can be directly compared with DD:

Natural synergy between accelerator-based and direct detection experiments.

DM as a product of secluded annihilation via a light scalar

a simple but UV complete model, fully compliant with astroparticle & cosmology (CMB)

$$\mathrm{DM\ DM} \to S^* S^* \to \mathrm{SM\ SM\ SM\ SM}$$



Astroparticle,
Cosmology
(SN 1987A, BBN)

Lower bound in coupling strength if DM is a thermal relic….

PBC projects:
NA62-Kaon, NA62-dump, KLEVER, FASER(2), CODEX-b, SHiP, MATHUSLA,…

Worldwide landscape:
MicroBooNE, KOTO, DarkQuest, Belle-II, LHCb, ATLAS, CMS

Major LABs involved:
CERN, KEK, JPARC, FNAL,…

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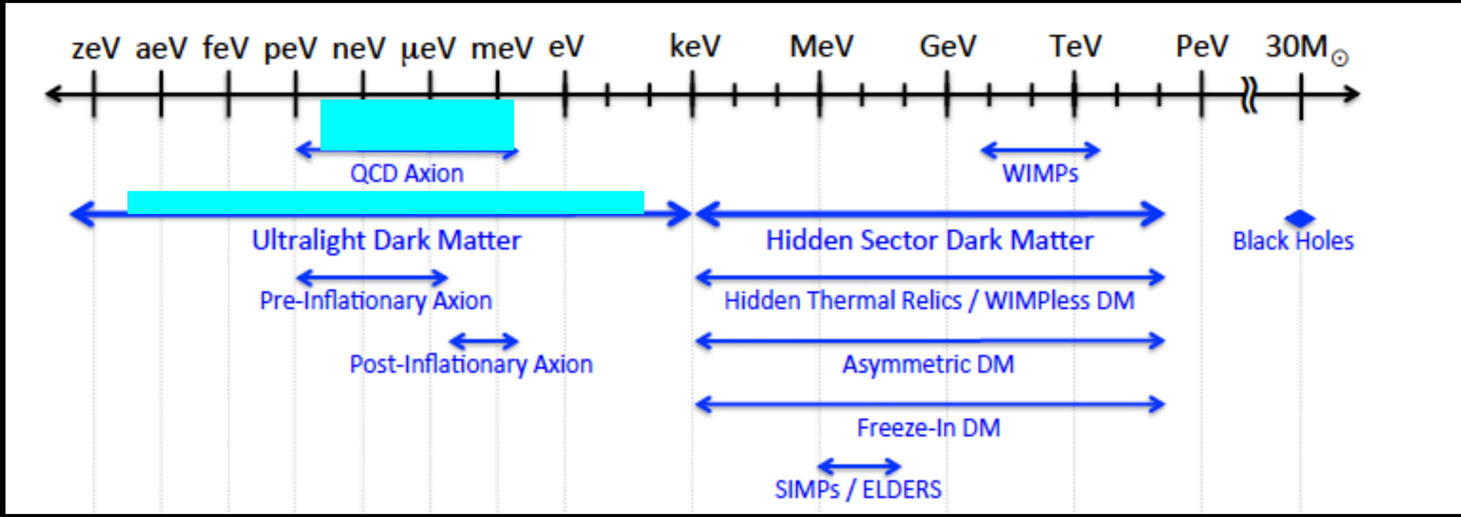
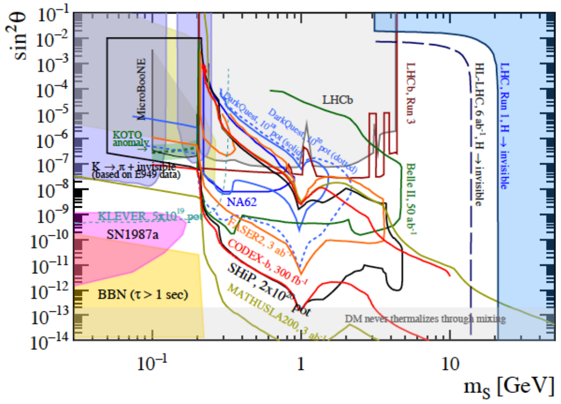


Cosmic Visions, arXiv:1707.04591

A light scalar as a non-thermal bosonic DM condensate

a simple but UV complete model, fully compliant with astroparticle & cosmology (CMB)



Accelerator-based experiments

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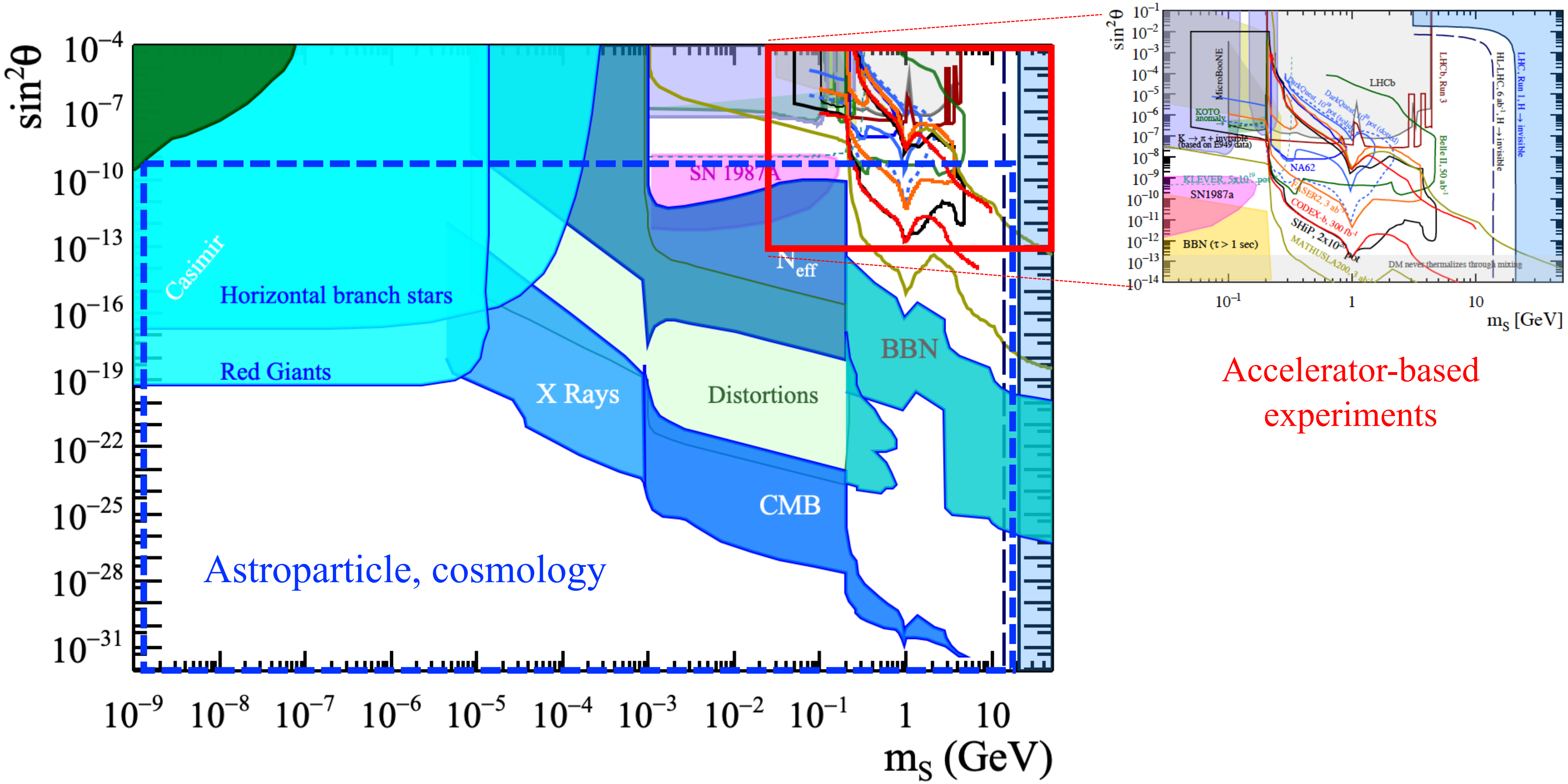

Astroparticle, cosmology go deep inside in the "natural" region of parameter space covering 10 orders of magnitude in mass and 20 in coupling.

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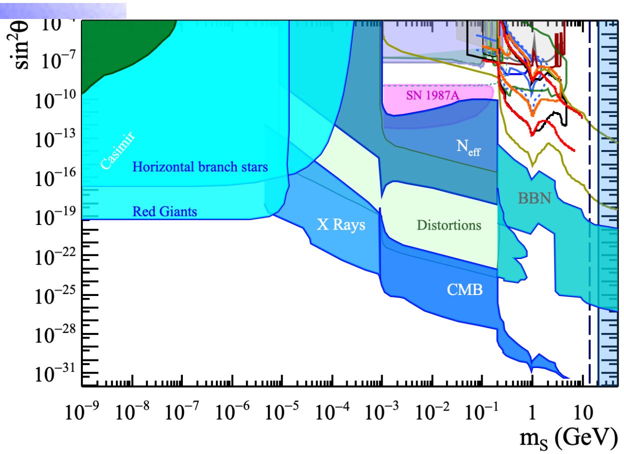

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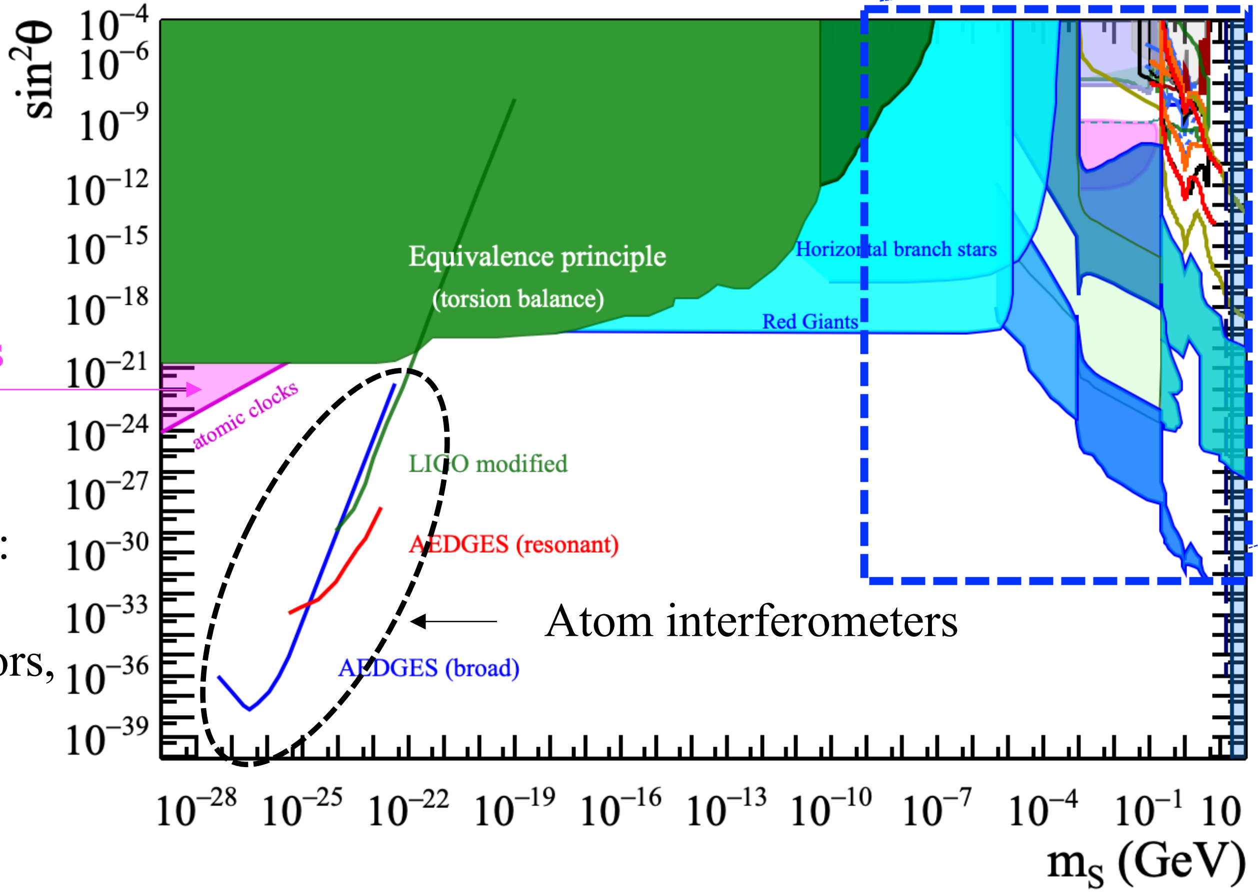
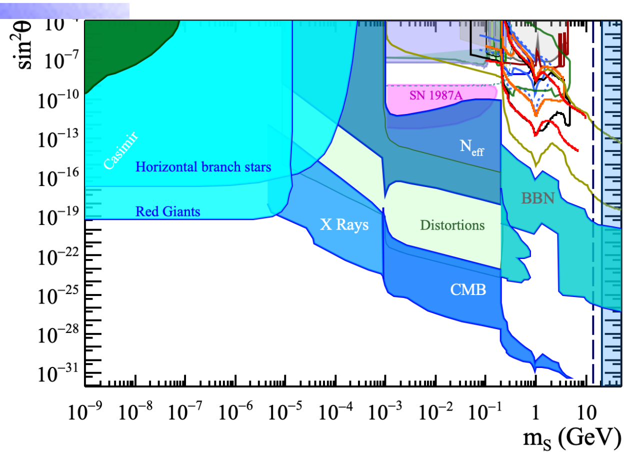
Atomic clocks

Ultra-light DM searches with:
atom interferometry,
atomic clocks, quantum sensors,
emerging technologies,…

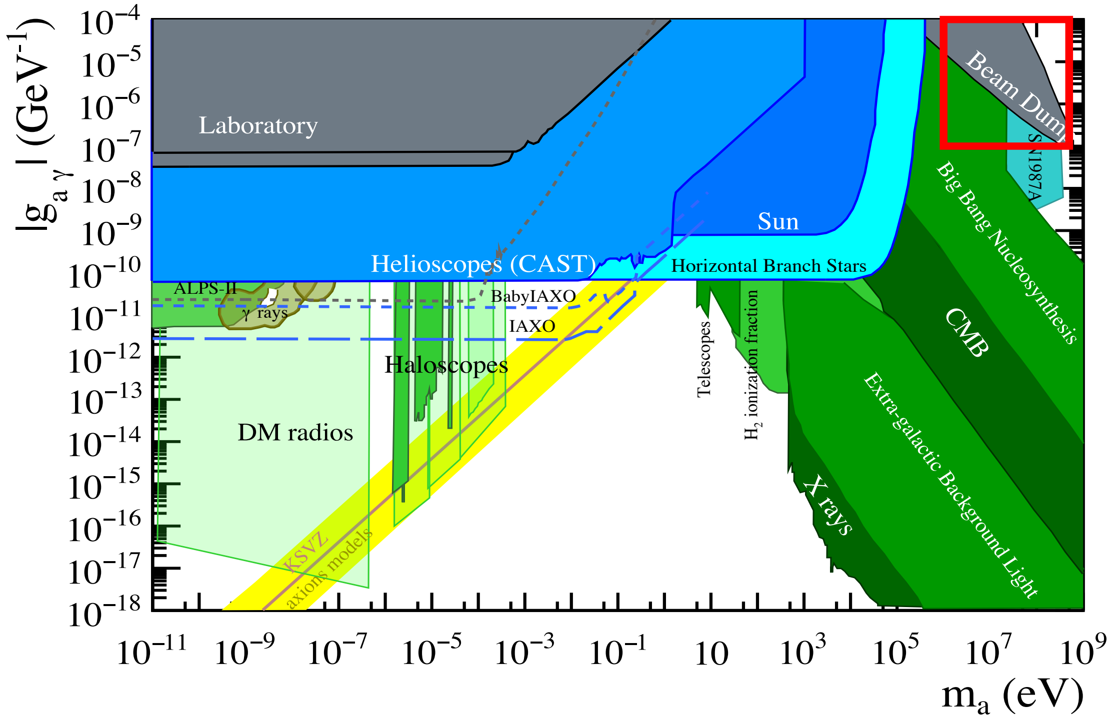


Atom interferometers



In the same mass range we can search for axions/ALPs……

A light axion/ALP as a non-thermal bosonic DM condensate

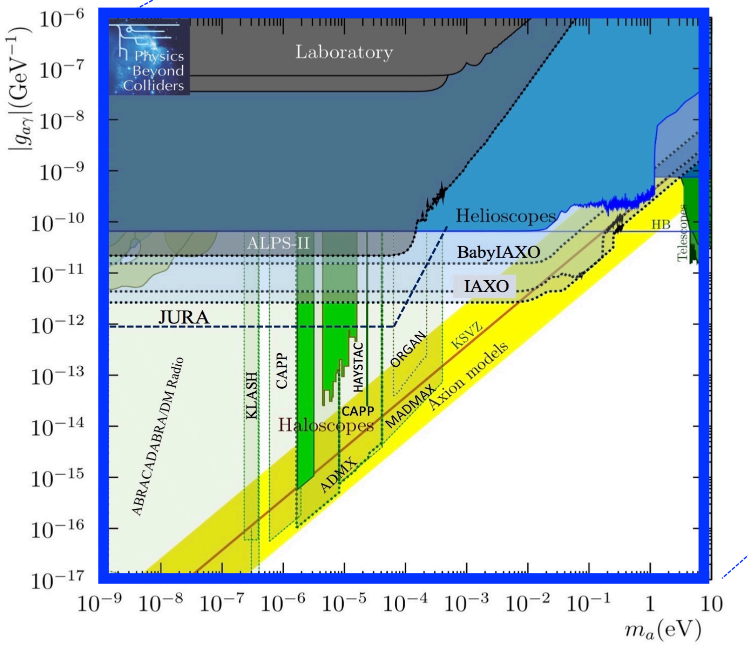


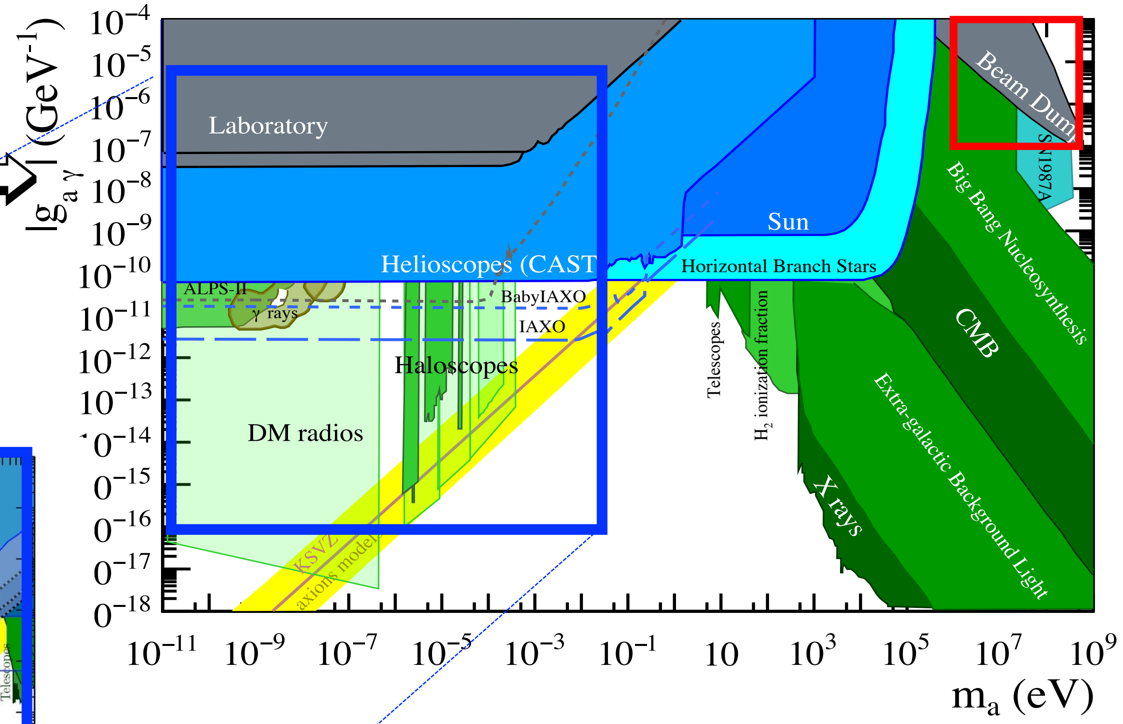
The search for axions: A worldwide effort.

A light axion/ALP as a non-thermal bosonic DM condensate

sub-eV range accessible at helioscopes and haloscopes

Here axion/ALP can be DM





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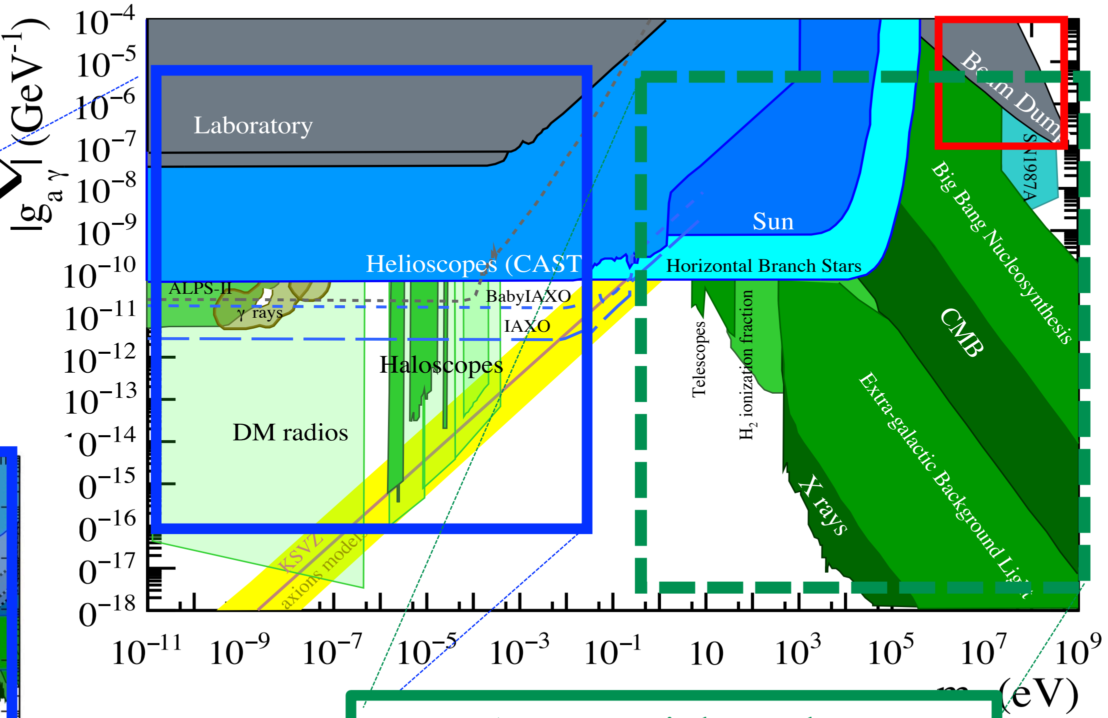
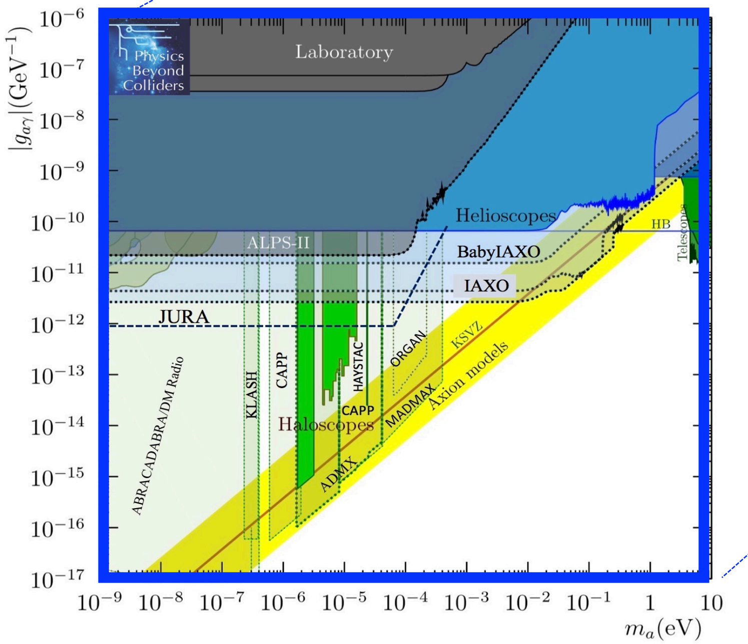


Here axion/ALP can be DM

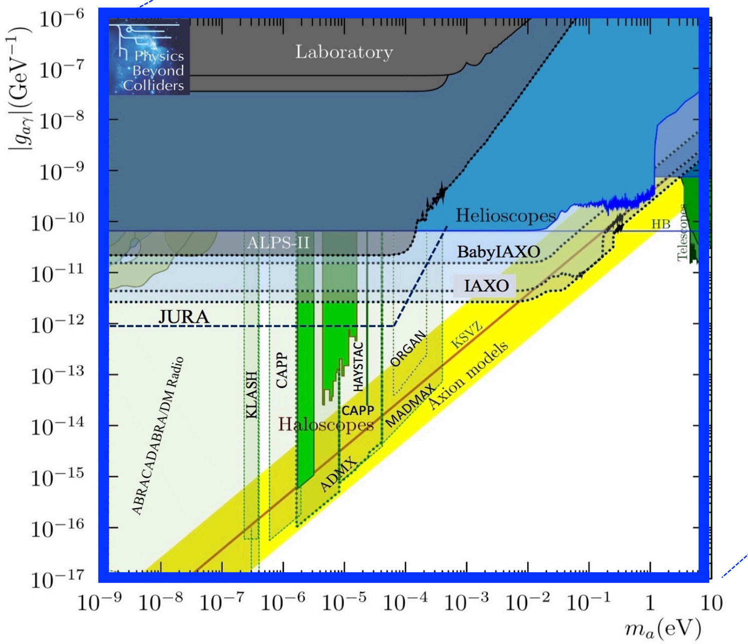


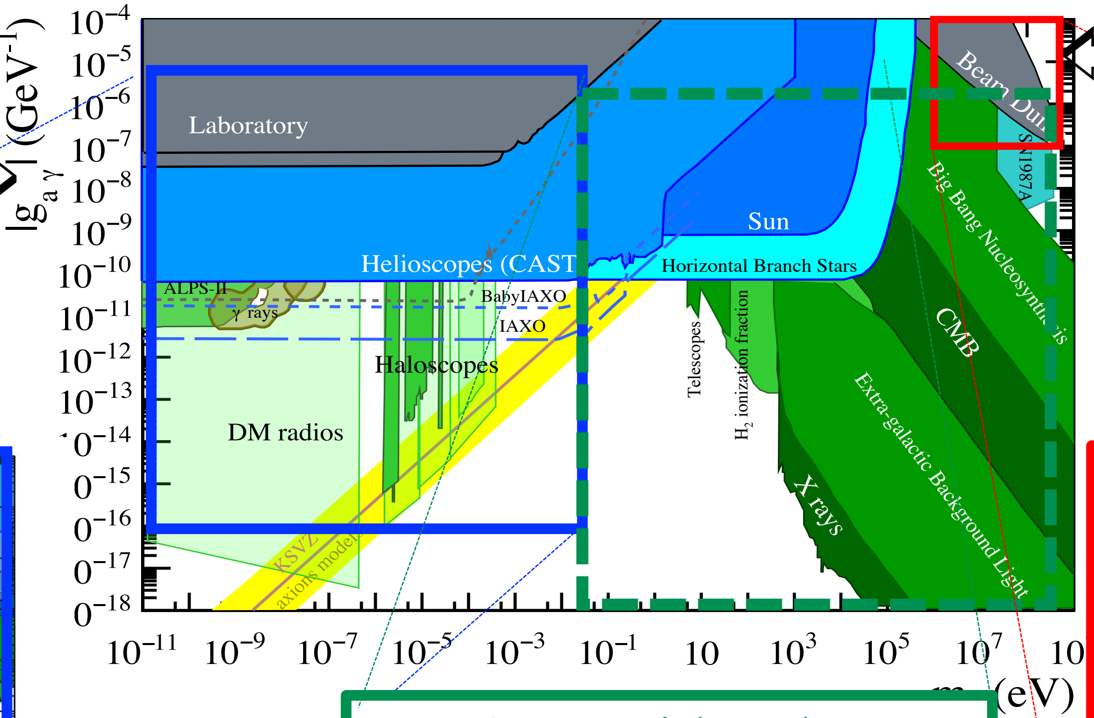
Astroparticle realm:
BBN, CMB, X-rays, SN1987,
Solar lifetime, etc..

An axion/ALP in the QCD scale range

sub-eV range accessible at helioscopes and haloscopes

Here axion/ALP can be DM

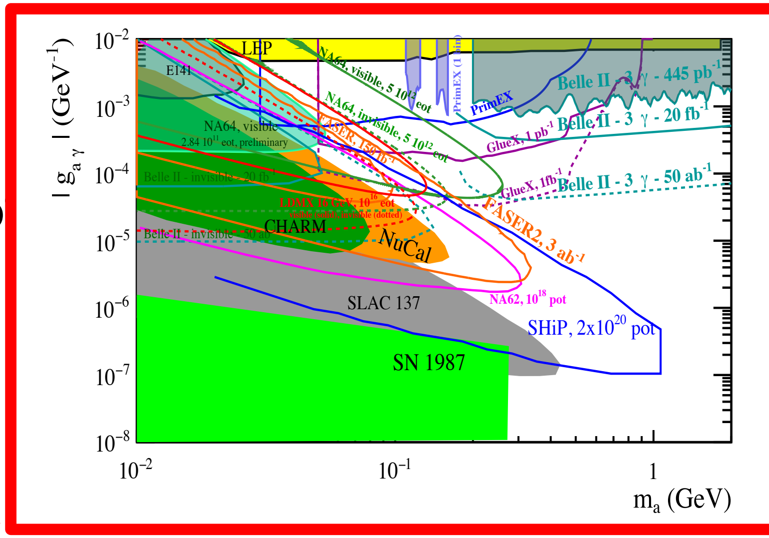




Astroparticle realm:
BBN, CMB, X-rays, SN1987,
Solar lifetime, etc..

MeV-10 GeV range accessible at accelerator based experiments

Here ALP can be mediator



What FIPs can provide us?

Not only DM but also heavy neutrinos…

1) Thermal DM candidates that extend the WIMP paradigm.
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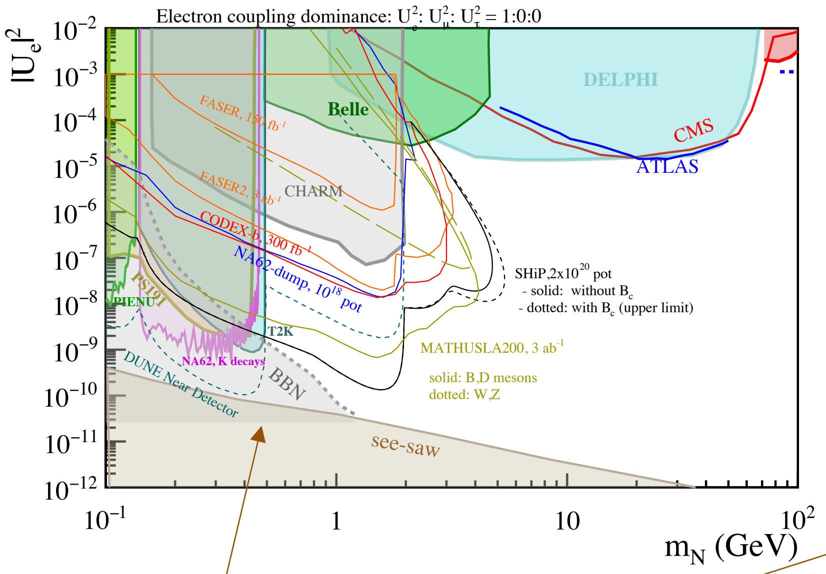
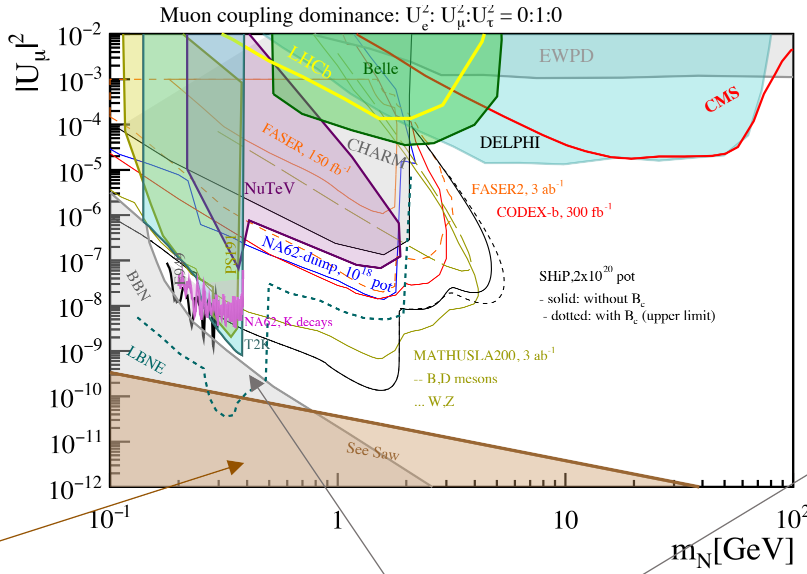
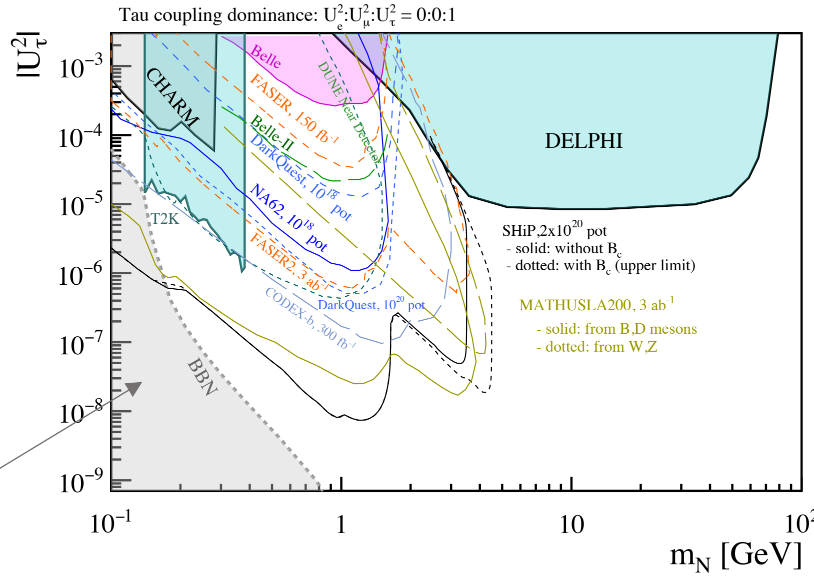
Heavy Neutral Leptons as Heavy Neutrinos?

current worldwide status for couplings to the three lepton generations







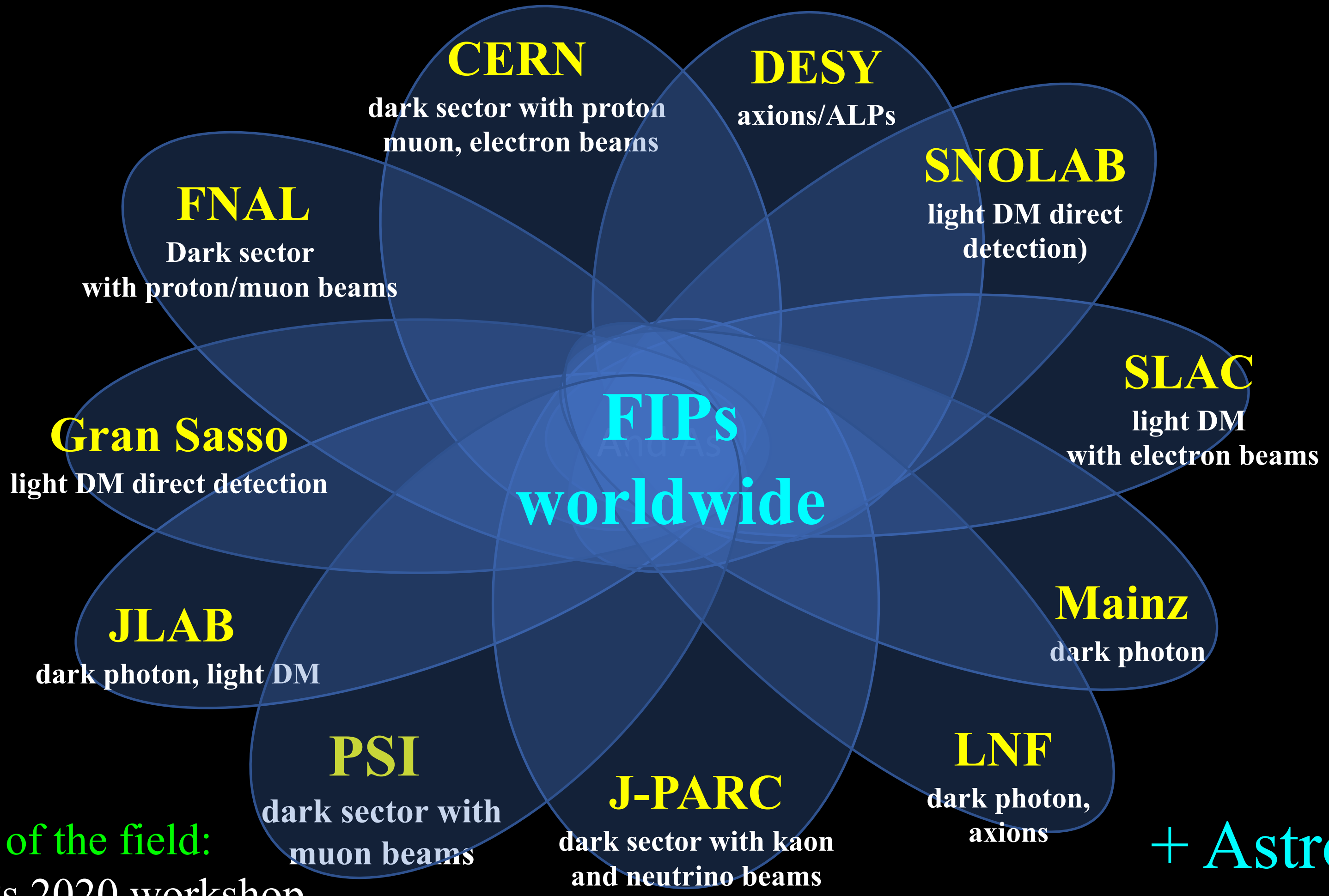
The seesaw line depends on the knowledge of $m_{lightest}$ which in turn depends on the knowledge of the sum on the light neutrino masses (SKA, Euclid, GC, ….)

BBN: HNLs must decay before BBN in order to not affect abundances of primordial elements observationally well constrained.

PBC experiments/projects: NA62-dump, NA62-Kaon, CODEX-b, FASER(2), MATHUSLA, SHiP, …
Worldwide landscape: ATLAS, CMS, LHCb, T2K, Belle-II, DarkQuest, DUNE near detectors, …
Labs involved: CERN, KEK, JPARC, FNAL, …

A lively field.

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

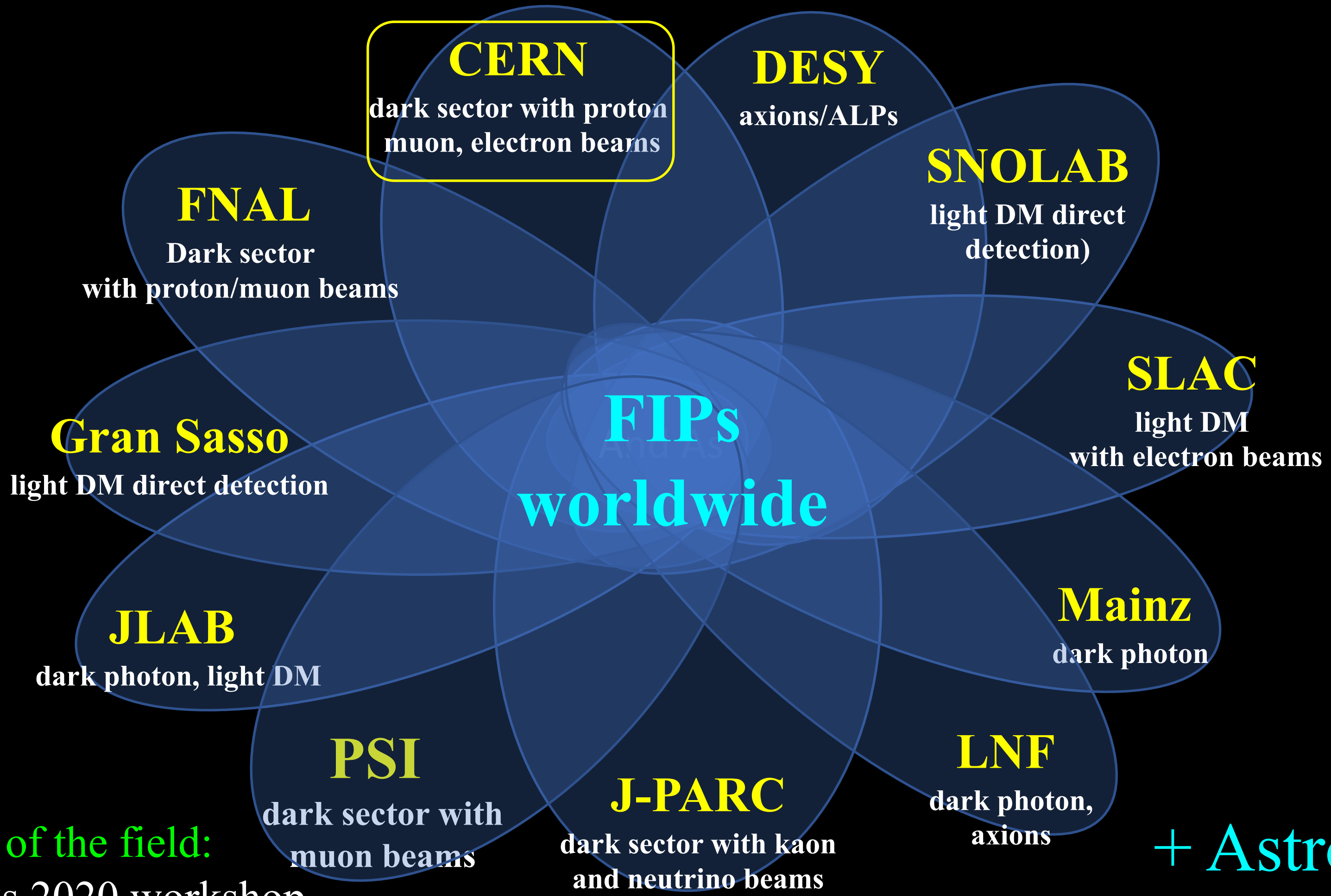


+ Astroparticle, cosmology

For a recent overview of the field:

- Proceedings of FIPs 2020 workshop,
- *Eur.Phys.J.C* 81 (2021) 11, 1015
- e-Print: 2102.12143 [hep-ph]

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



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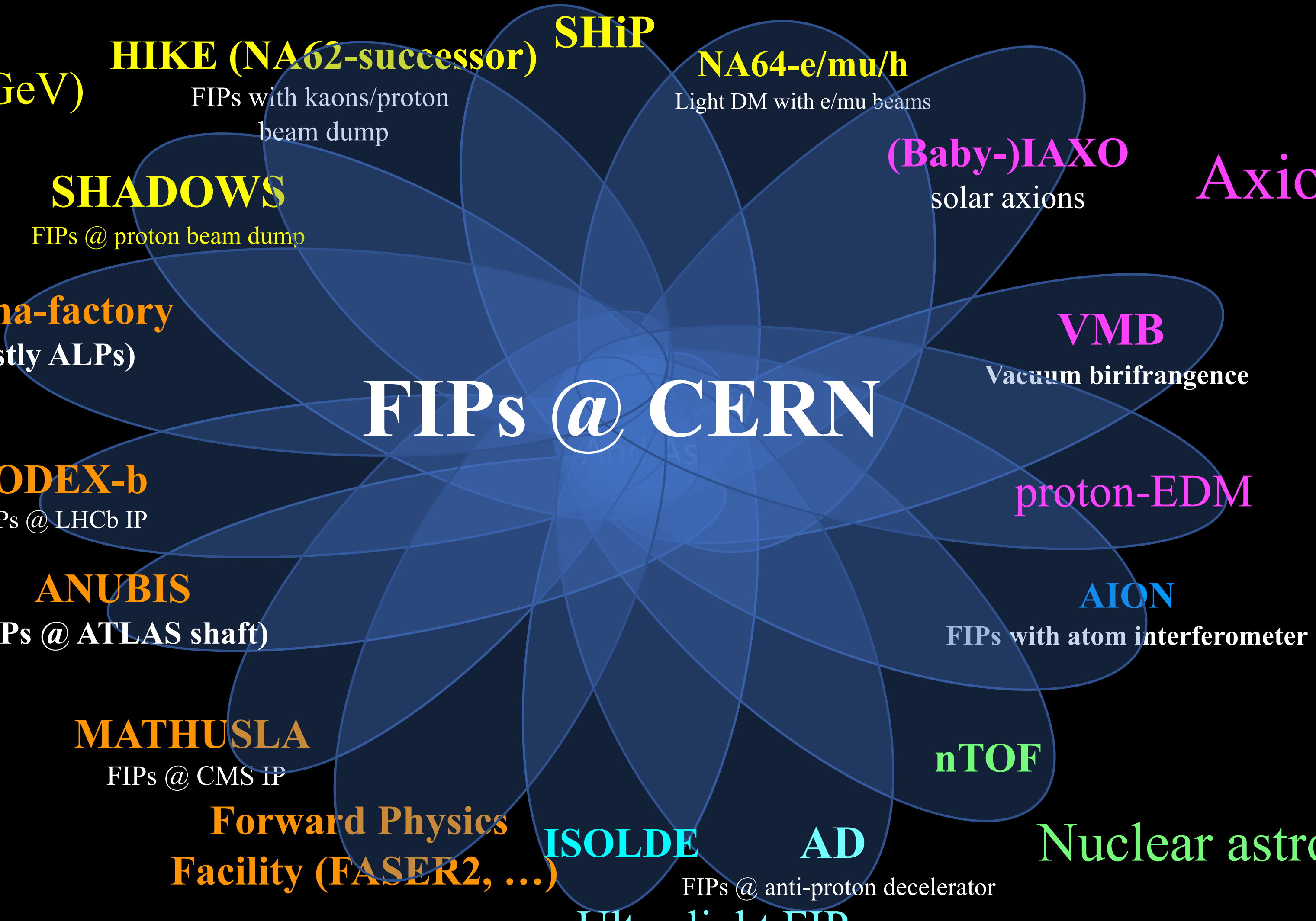
Experiments/proposals related to FIPs in PBC

Physics Beyond Colliders

SPS
(MeV- few GeV)



Axions/Dark Photons
(< meV)

LHC
(few GeV – TeV)

Gravitational Waves
via atom interferometry
(10^{-20} eV)

Nuclear astrophysics

Ultra-light FIPs
(atomic clocks, quantum sensors and the likes)

Physics Beyond Colliders

The new PBC mandate

"The main goal of the Study Group remains to explore the opportunities offered by CERN's unique accelerator complex, its scientific and technical infrastructure, and its know-how in accelerator and detector science and technology, to address today's outstanding questions in particle physics through initiatives that complement the goals of the main experiments of the Laboratory's collider programme.

Examples of physics objectives include dedicated experiments for studies of rare processes and searches for feebly interacting particles.

The physics objectives also include projects aimed at addressing fundamental particle physics questions using the experimental techniques of nuclear, atomic, and astroparticle physics, as well as emerging technologies such as quantum sensors, that would benefit from the contribution of CERN competences and expertise.

The study group will primarily investigate, and, where appropriate, provide support to, projects expected to be sited at CERN. The study group may also examine ideas and provide initial support for contributions to projects external to CERN. The study group is also expected to act as a central forum for exchanges between the PBC experimental community and theorists for assessment of the physics reach of the proposed projects in a global landscape. "

Physics Beyond Colliders budget: ~20 MCHF in 5 years

CERN Medium Term Plan 2022-2026

CERN/SPC/1158/Rev.
CERN/FC/[illegible]/Rev.
CERN/3575
Original: English
2 June 2021

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting procedure*
For recommendation to the Council	SCIENTIFIC POLICY COMMITTEE 323rd Meeting 14-15 June 2021	–
For recommendation to the Council	FINANCE COMMITTEE 377th Meeting 16 June 2021	Chapters I and IV.1: Simple majority of Member States represented and voting (abstentions are not counted) and 70% of the contributions of the Member States represented and present for the voting (abstentions are counted as votes against) and at least 51% of the contributions of all Member States. Chapter III: Two-thirds majority of Member States represented and voting (abstentions are not counted) and 70% of the contributions of the Member States represented and present for the voting (abstentions are counted as vote against) and at least 51% of the contributions of all Member States.
For decision	RESTRICTED COUNCIL 203rd Session 17-18 June 2021	Chapters I and IV.1: Simple majority of Member States represented and voting (abstentions are not counted). Chapter III: Two-thirds majority of Member States represented and voting (abstentions are not counted).

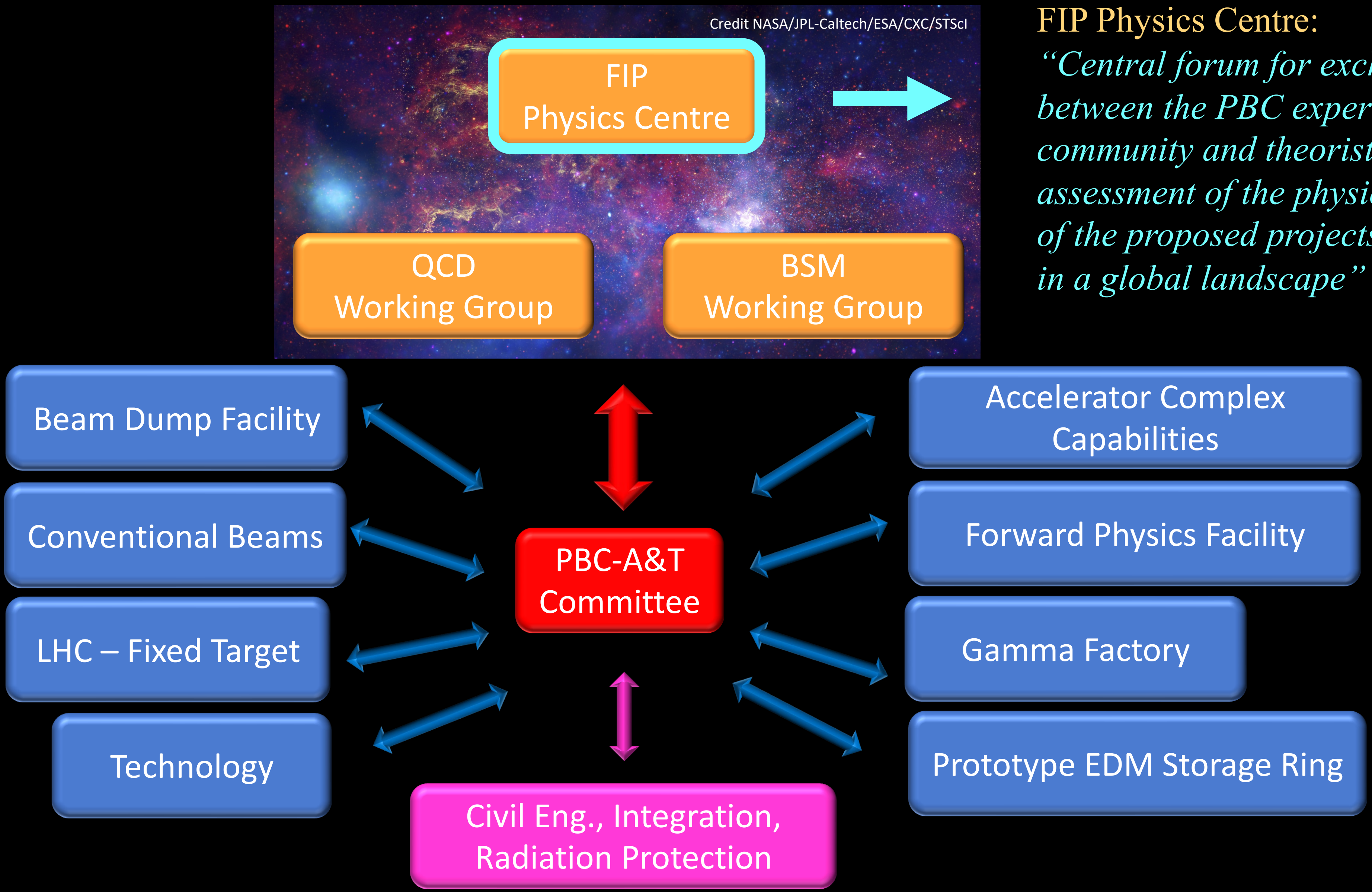
Medium-Term Plan for the period 2022-2026 and Draft Budget of the Organization for the sixty-eighth financial year 2022

GENEVA, June 2021

- *…….A diverse scientific programme is strongly supported by the 2020 Strategy update, which also recognised the role of the Physics Beyond Colliders (PBC) study group as the focal point for promoting and channelling new research initiatives………*
- *………Given the importance of a diverse scientific programme to addressing the outstanding questions in particle physics in a way complementary to high-energy colliders PBC activities are funded with an increased budget of ~3.5 MCHF/year in this MTP (up from 1 MCHF/year)*

Scientific projects	**284.8**	**341.0**	**330.1**	**318.2**	**272.6**	**209.9**	**1 757**
LHC upgrades	**212.1**	**234.0**	**228.7**	**218.4**	**184.5**	**137.3**	**1 215**
LHC injectors upgrade (LIU)	*7.4*						*7*
HL-LHC upgrade	*162.9*	*159.7*	*156.6*	*150.5*	*131.7*	*98.0*	*860*
LHC detectors upgrades (Phase I) and consolidation	*7.9*	*3.8*	*2.0*	*2.0*	*1.0*	*2.2*	*19*
LHC detectors upgrades (Phase II) and R&D	*33.9*	*70.5*	*70.1*	*65.8*	*51.8*	*37.1*	*329*
Future colliders studies	**18.6**	**27.5**	**33.0**	**31.3**	**22.9**	**19.8**	**153**
Linear collider	*5.4*	*5.1*	*4.7*	*4.2*	*4.1*		*23*
Future Circular Collider	*11.7*	*20.2*	*26.3*	*25.1*	*16.8*		*100*
Muon colliders	*1.5*	*2.3*	*2.0*	*2.0*	*1.9*		*10*
High-energy frontier						*19.8*	*20*
Accelerator technologies and R&D	**26.8**	**35.5**	**31.5**	**28.6**	**31.3**	**28.2**	**182**
R&D for future detectors	**7.5**	**8.0**	**7.7**	**7.3**	**4.1**	**4.1**	**39**
Scientific diversity projects	**19.7**	**36.1**	**29.3**	**32.6**	**29.9**	**20.5**	**168**
Neutrino Platform	*8.8*	*23.0*	*17.1*	*20.0*	*18.4*	*9.0*	*96*
Physics Beyond Colliders	*2.3*	*4.2*	*3.7*	*3.5*	*3.3*	*3.3*	*20*
EU supported computing R&D, support to external facilities	*8.7*	*8.9*	*8.5*	*9.1*	*8.2*	*8.2*	*51*

May 2021: The New PBC Structure



FIP Physics Centre:

"Central forum for exchanges between the PBC experimental community and theorists for assessment of the physics reach of the proposed projects in a global landscape"

Physics Beyond Colliders

FIP Physics Centre

Contacts: Maxim Pospelov & GL

Mikhail Shaposhnikov (HNL)

Gian Francesco Giudice (Head of CERN-TH)

Philip Harris (DM LHC WG)

Yevgeni Stadnik (ultra-light FIPs)

Stefania Gori (light DM)

Albert De Roeck (LLP @ LHC)

Marco Drewes (HNL)

Joerg Jaeckel (axions/ALPs)

Torben Ferber (Belle II)

Stefan Ulmer (ultra-light FIPs)

Maurizio Giannotti (stars)

Silvia Pascoli (HNL)

Jocelyn Monroe (DM DD)

James Beacham (LLP @ LHC)

Igor Irastorza (axion physics)

Jessie Shelton (astroparticle)

Jacobo Lopez-Pavon (HNL)

Felix Kahlhoefer (Axions,ALPs,..)

+ one representative per PBC experiment related to FIP physics

FPC ACTIVITY (1/2)

We see the FPC activity divided in three main areas:
"Work with experiments", "Work with theorists", and "General":

1) Work with PBC experiments:

- Propose benchmarks;
- Discuss results from PBC experiments.
- Harmonize results one another (check that they are produced using the same assumptions)
- Collect results from non-PBC experiments related to FIP physics.
- Put results in worldwide context.
- Compile and document summary plots.
- Propose recipe to publish results in a way that can be easily re-interpreted following the fast theory progress (efficiency maps as a function of lifetime, background in bins, etc.).

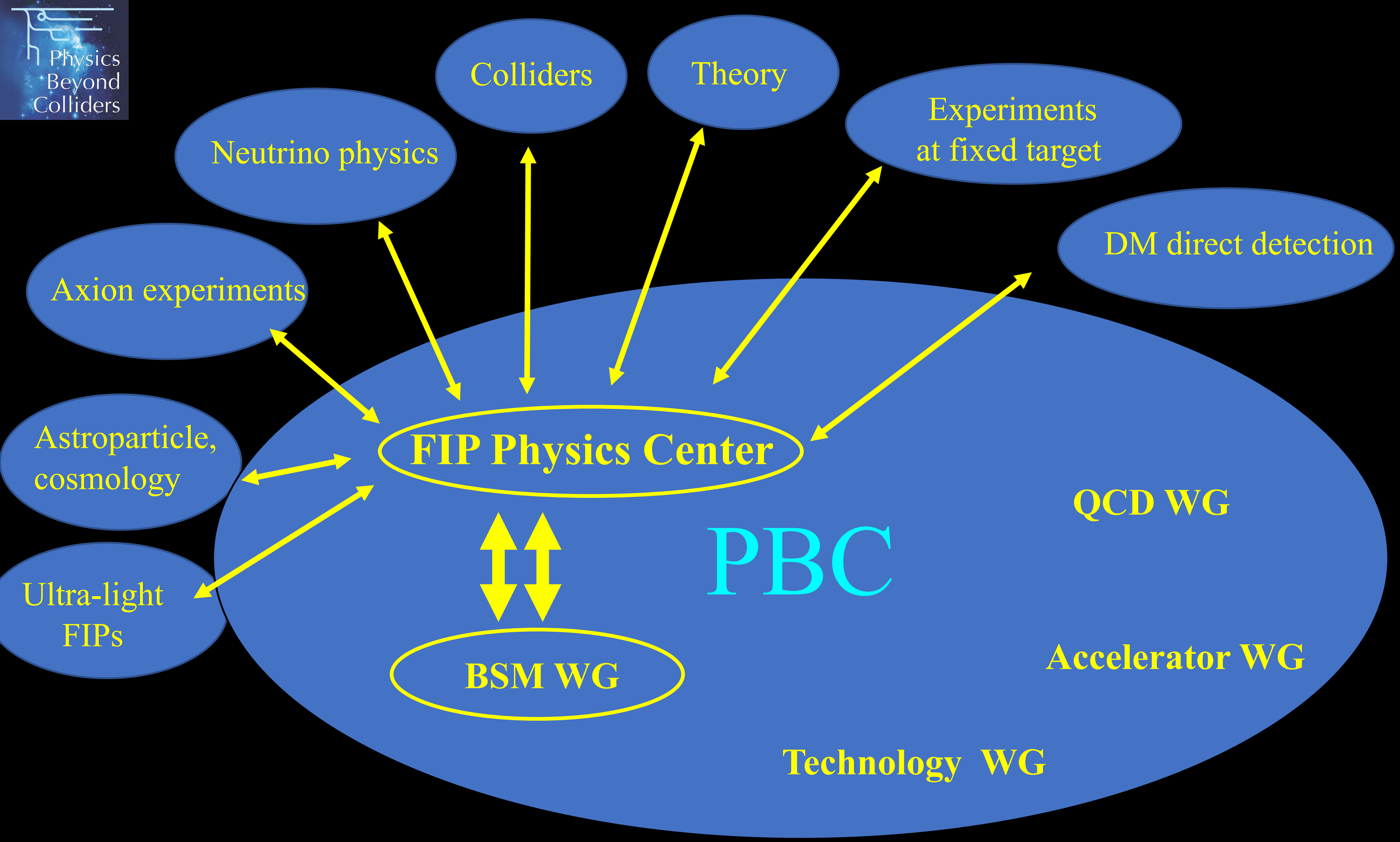
FPC ACTIVITY (2/2)

2) Work with theorists:

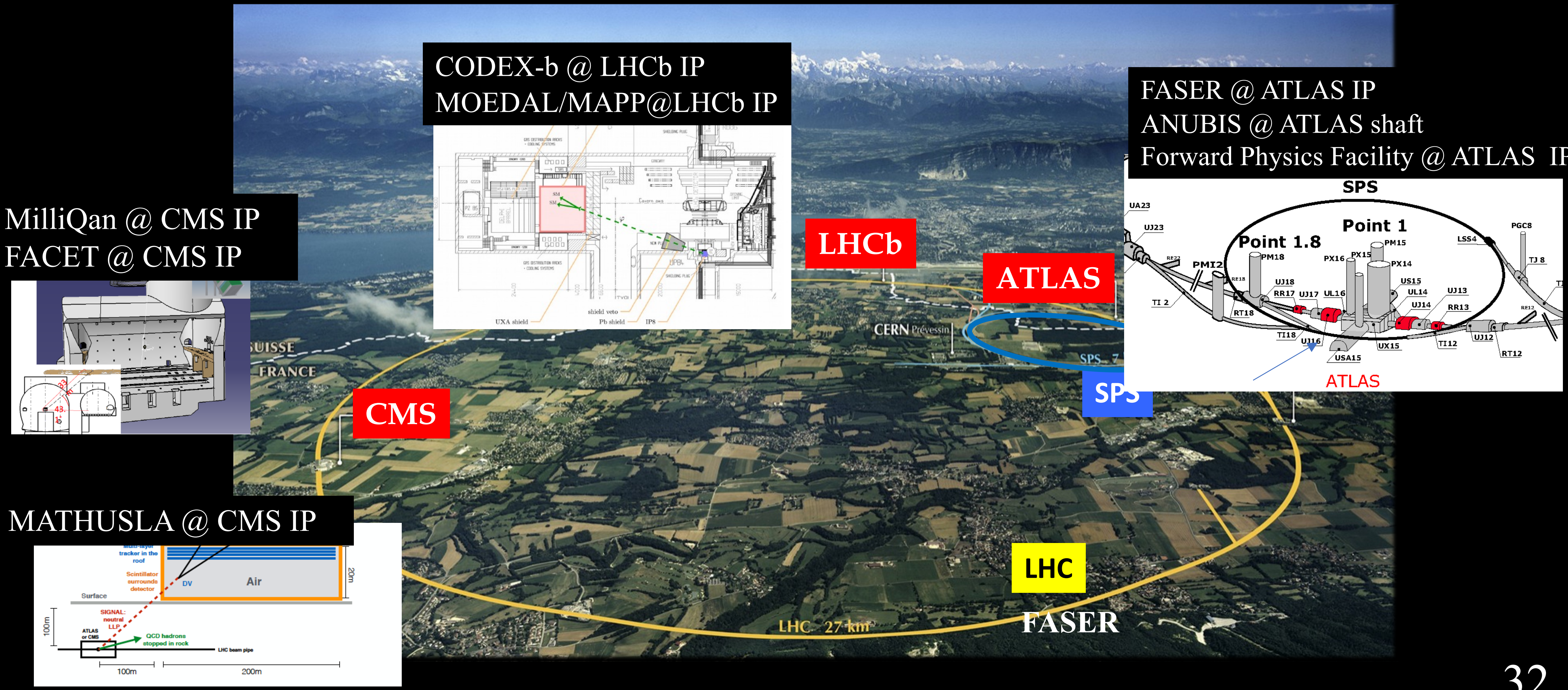
- develop/propose/improve benchmarks starting from (as much as possible) complete models;
- define, within a given benchmark, connections with (and bounds from) neighboring fields:
  - light DM MeV-GeV results at accelerator vs direct detection exps;
  - astro/cosmo bounds;
  - ultra-light FIPs;
  - active neutrino physics

3) General:

- Follow closely experimental and theory advances. Report at the meetings.
- Organize seminars on “hot topics” related to FIPs physics.
- Keep connections with neighboring communities/efforts (eg: YOU!).


Physics Beyond Colliders
Colliders
Theory
Neutrino physics
Experiments at fixed target
DM direct detection
Axion experiments
Astroparticle, cosmology
Ultra-light FIPs
FIP Physics Center
BSM WG
PBC
QCD WG
Accelerator WG
Technology WG

FIPs @ CERN –The Long-Lived Particle detectors at the LHC IPs



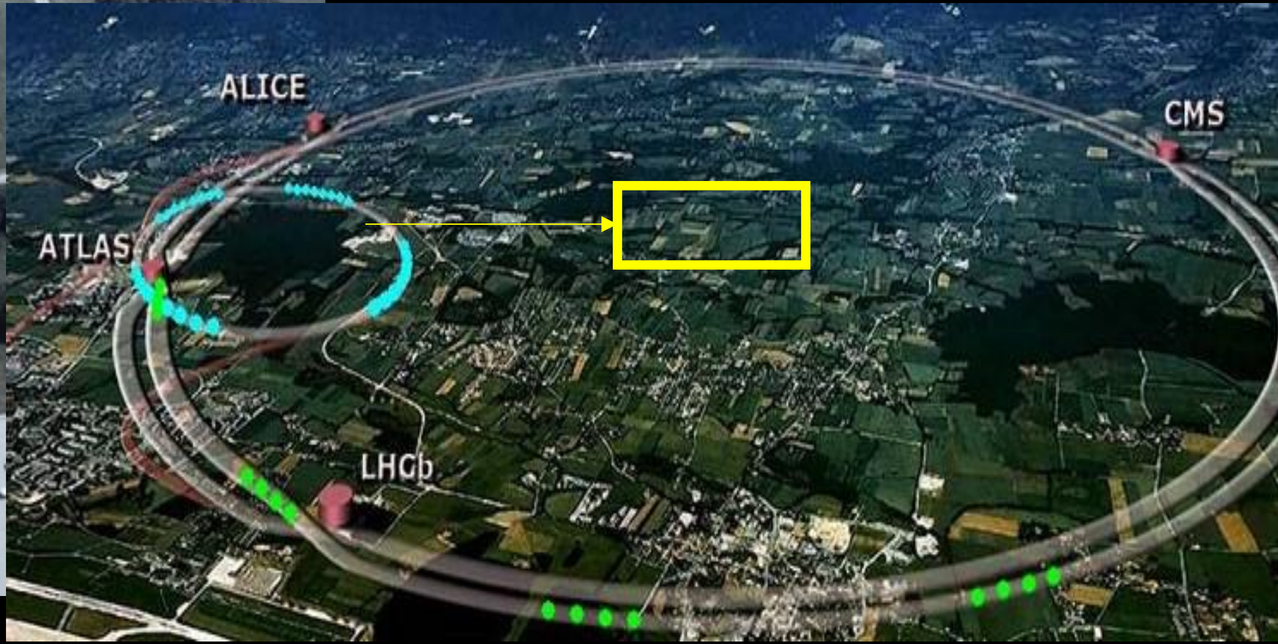
+ an active LLP community inside ATLAS, CMS, and LHCb collaborations

FIPs @ CERN – The North Area: a unique infrastructure…

ECN3:
P42/K12: 400 GeV p beam
up to 3x10^{18} pot/year (now)
→ **NA62**
up to a few 10^{19} pot/year (proposed)
→ **HIKE, SHADOWS, SHiP**

EHN1:
H4: 100 GeV e- beam
up to 5x10^{12} eot/year
→ **NA64^{++} (e), NA64^{++}(hadrons)**

EHN2:
M2: 100-160 GeV, mu beam
up to 10^{13} μ/year
→ **NA64^{++} (mu)**

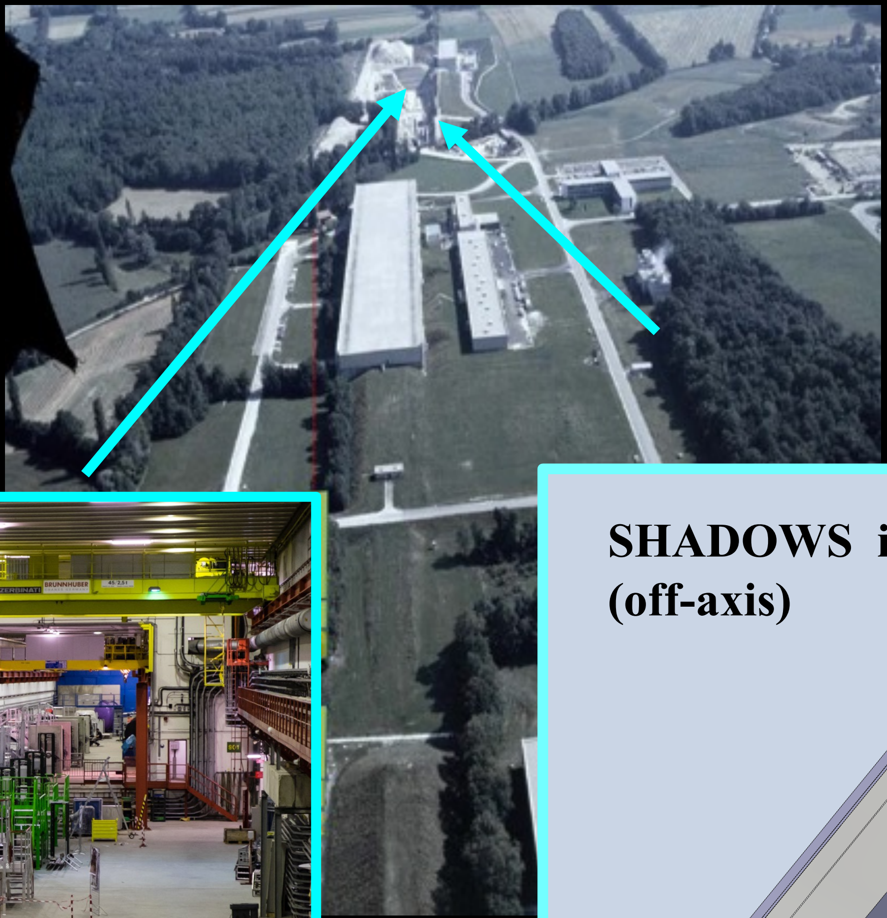


… to search for FIPs at extracted beam lines

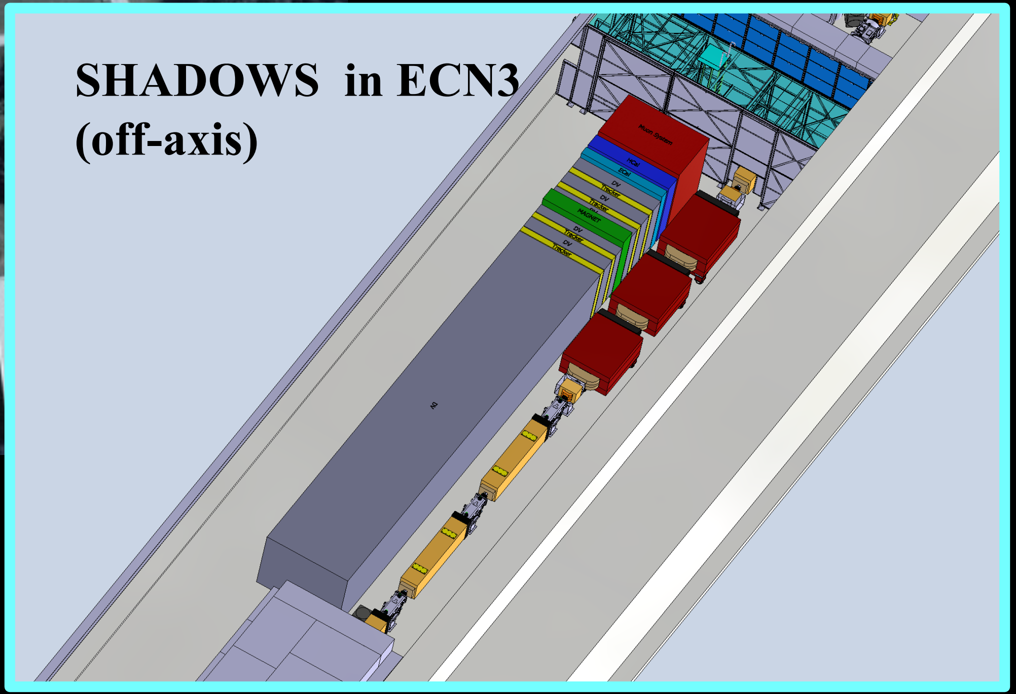
A Hidden Sector Campus.

FIPs @ CERN – HIKE & SHADOWS

ECN3:
P42/K12: 400 GeV p beam
up to $3\text{x}10^{18}$ pot/year (now)
→ **NA62**
up to a few 10^{19} pot/year
→ **HIKE & SHADOWS**

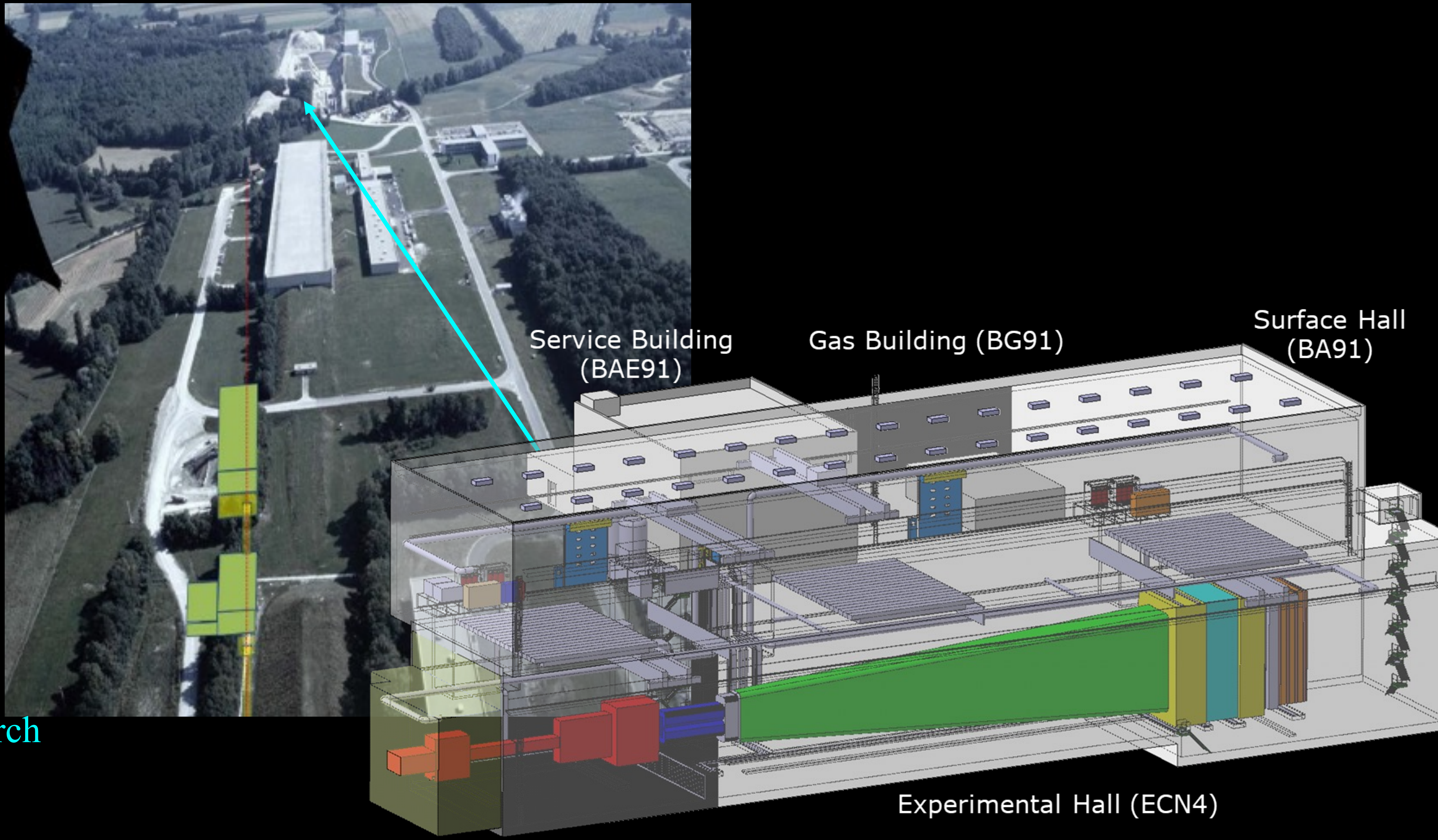


NA62 in ECN3



SHADOWS in ECN3
(off-axis)

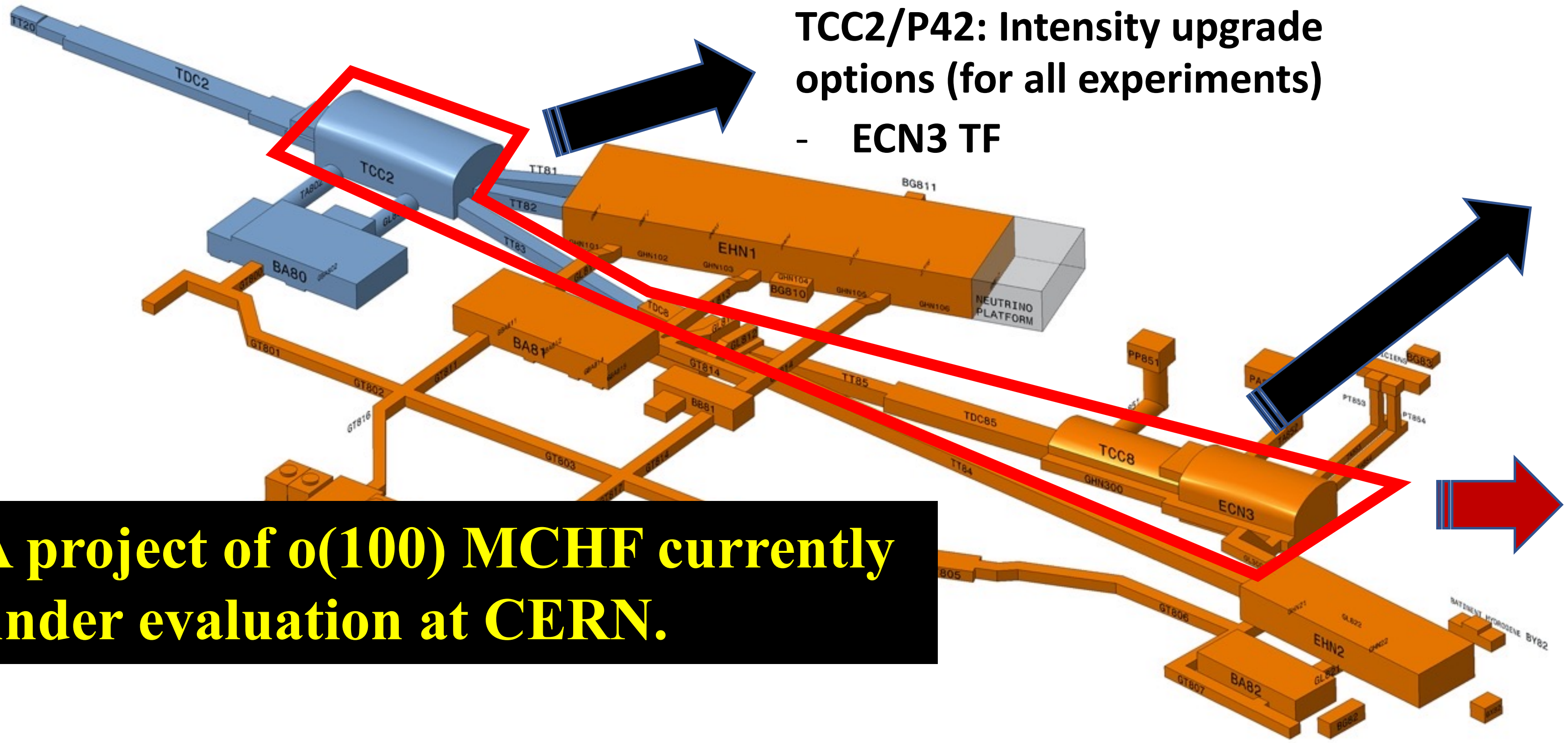
FIPs @ CERN – SHiP @ ECN3



SHiP@ BDF
A multipurpose experiment for search for FIPs at large

NA-CONS - Intensity Upgrade Project

Consolidation Phase 1 (funded):
2019 – 2027: primary areas, BA80 & beamlines towards EHN1 & TDC8



TCC2/P42: Intensity upgrade options (for all experiments)
- **ECN3 TF**

TCC8/ECN3: Experiment specific:
- **BDF/SHIP WG**
- **CBWG**

Beam Areas concerned with the upgrade of ECN3 to a high intensity facility

A project of o(100) MCHF currently under evaluation at CERN.

Consolidation Phase 2 (not yet funded):
2028 – 2033: BA81, BA82, EHN1, EHN2 & associated beamlines

The FIPs 2022 Workshop

- 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 2020 edition (FIPs 2020) :**

e-Print 2102.12143 [hep-ph], *Eur.Phys.J.C* 81 (2021) 11, 1015
got in ~18 months about 152 citations and are becoming a reference worldwide.

- Proceedings of the 2022 edition will be even better…(will be published in a month or so)

FIPs 2022 Proceedings: Table of Contents

Contents

Currently 240+ pp long
Contains the state-of-the-art of our field.

Proceedings will be submitted
to arXiv and to EPJC.

The recent article on the CERN Courier

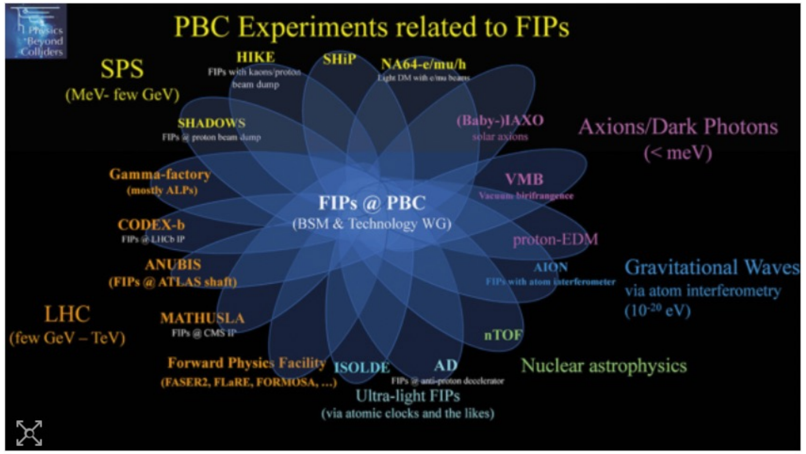
https://cerncourier.com/a/chasing-feebly-interacting-particles-at-cern/

CERNCOURIER | Reporting on international high-energy physics

SEARCHES FOR NEW PHYSICS | MEETING REPORT

Chasing feebly interacting particles at CERN

11 January 2023



FIPS@CERN New experiments for hunting feebly interacting particles (FIPs) at CERN were discussed. Credit: G Lanfranchi

What is the origin of neutrino masses and oscillations? What is the nature of Dark Matter? What mechanism generated matter-antimatter-asymmetry? What drove the inflation of our Universe and provides an explanation to Dark Energy? What is the origin of the hierarchy of scales? These are outstanding questions in particle physics that still require an answer.

So far, the experimental effort has been driven by theoretical arguments that favoured the existence of new particles with relatively large couplings to the Standard Model (SM) and masses commensurate the mass of the Higgs boson. Searching for these

The « FIPs in the ALPs » school

https://indico.cern.ch/event/1247323/

FIPs in the ALPs

School on Feebly Interacting Particles

14-19 May 2023, Les Houches, France

14–19 May 2023
Europe/Zurich timezone

Overview
Timetable
Registration
Practical Information
- How to get to Les Houches
- Directions to Hostel/Meeting room
- Accommodation
- Access to Les Houches computing network

Participant List

Contacts
gaia.lanfranchi@lnf.infn.it
houches-secretariat@un…

FIPs in the ALPs is the first edition of a foreseen series of schools fully dedicated to the physics of feebly-interacting particles and aims to gathering together highly renowned experts from collider, beam dump, fixed target experiments, as well as from astroparticle, cosmology, axion/ALP, ultra-light particle searches, and dark matter direct and indirect detection communities along with a set of young and brilliant physicists to discuss progress in experimental searches and underlying theory models for FIP physics.

The school is organized by the FIP Physics Centre of the Physics Beyond Colliders study group at CERN: https://pbc.web.cern.ch/fpc-mandate

The aim of the school is to embedding a new generation of physicists into the activities of the study group.

The School is organized along three main directions:

1. **MeV-GeV Dark Matter** and its searches at accelerator, direct and indirect detection experiments;
2. **Heavy neutral leptons** and their connection to active neutrino physics;
3. **Ultra-light (< 1 eV) FIPs** in particle physics, astroparticle, and cosmology.

Advanced PhD students and PostDocs are strongly encouraged to apply.

Physics Beyond Colliders

https://indico.cern.ch/event/1247323/   80 %

The « FIPs in the ALPs » school

FIPs in the ALPs

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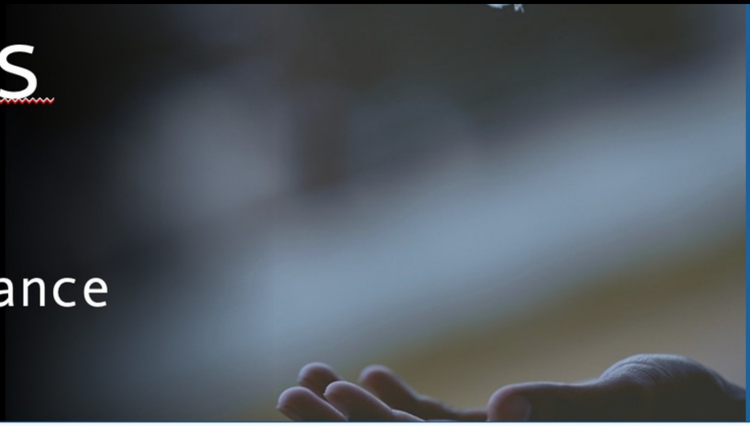

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Tentative programme:

- ***Marco Drewes, Mikhail Shaposhnikov:*** *Heavy Neutral Leptons in particle physics and cosmology*
- ***Maxim Pospelov:*** *FIPs in the early universe*
- ***Yevgeny Stadnik:*** *Phenomenology of ultra-light FIPs*
- ***Joerg Jaeckel:*** *ALPs in the FIPs*
- ***Stefania Gori:*** *Phenomenology of MeV-GeV Dark Matter*
- ***Gaia Lanfranchi:*** *FIPs at extracted beam lines.*

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Conclusions

FIP physics is a field in full expansion:
Started as an extension of the programme at colliders is now a stand-alone direction with connections with many other fields.

A very active experimental activity is matched with lively theoretical developments:
- the first dedicated experiments are beginning to be funded and
- a set of benchmarks recognized by the worldwide community are being developed by exploring also the diverse impact they have on neighboring fields.

FIP physics proposes a complementary approach with respect to the main stream:
- a network of interconnected laboratories looking at the same kind of physics from different viewpoints and different techniques with a set of small medium experiments rather than a single big project concentrated only in one place.

The community is reacting in a very positive way:
- the next new big discovery - to me - could come from here.

Physics Beyond Colliders

Thank you for your attention.