Physics Beyond Colliders at CERN

Gaia Lanfranchi - INFN

PPAP - European Strategy UK discussion - Birmingham, September 2021

Physics Beyond Colliders activity and the ESPP

http://pbc.web.cern.ch/

Physics Beyond Colliders

Main coordinators: Claude Vallee, Mike Lamont, Joerg Jackel

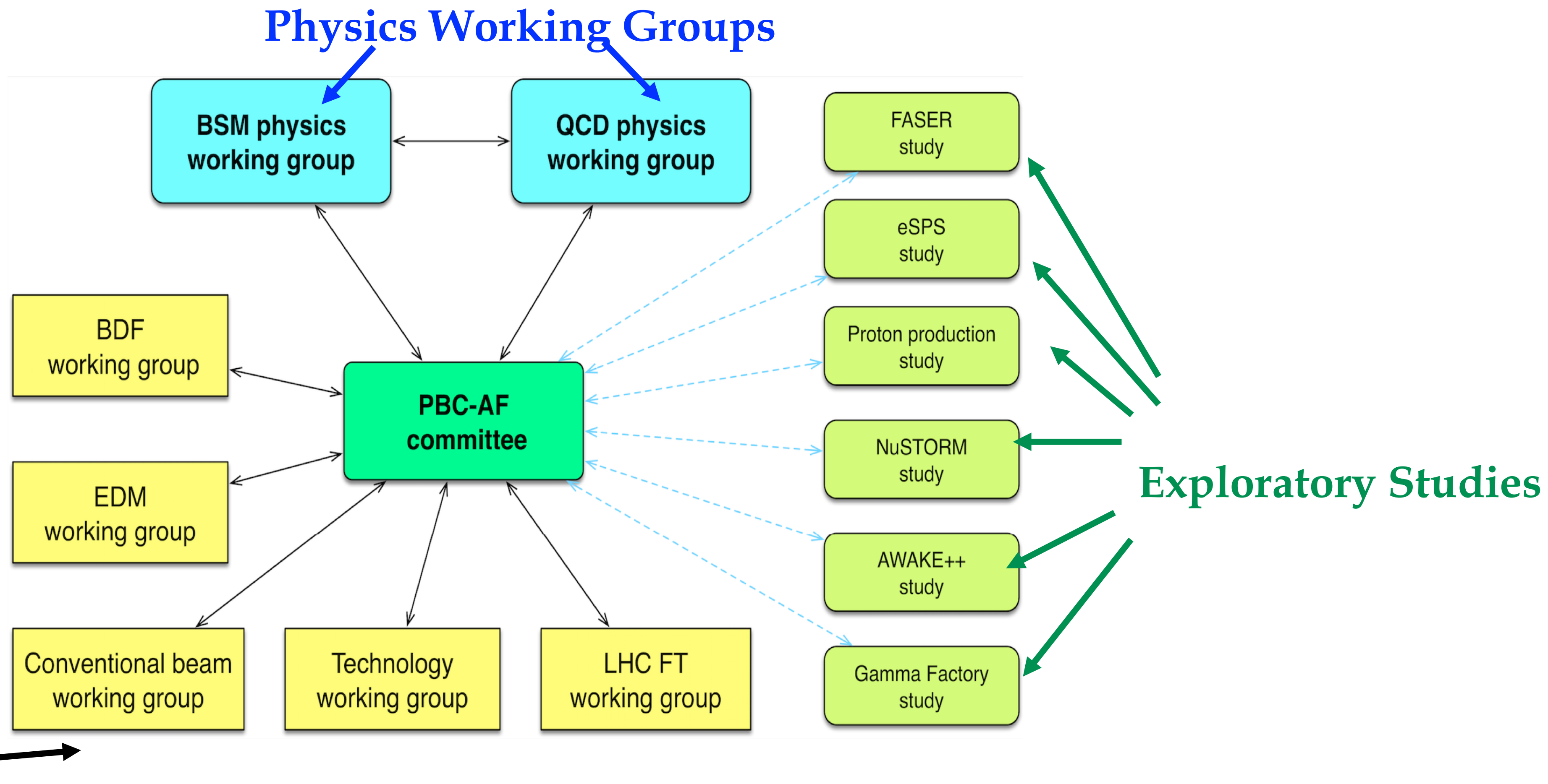
Organization **PBC@work** **Resources**

Physics Beyond Colliders is an exploratory study aimed at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure through projects complementary to the LHC, HL-LHC and other possible future colliders. These projects would target fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that require different types of beams and experiments. The mandate of the study team may be found here.

PBC will submit a series of documents to be used as input to the ESPP update

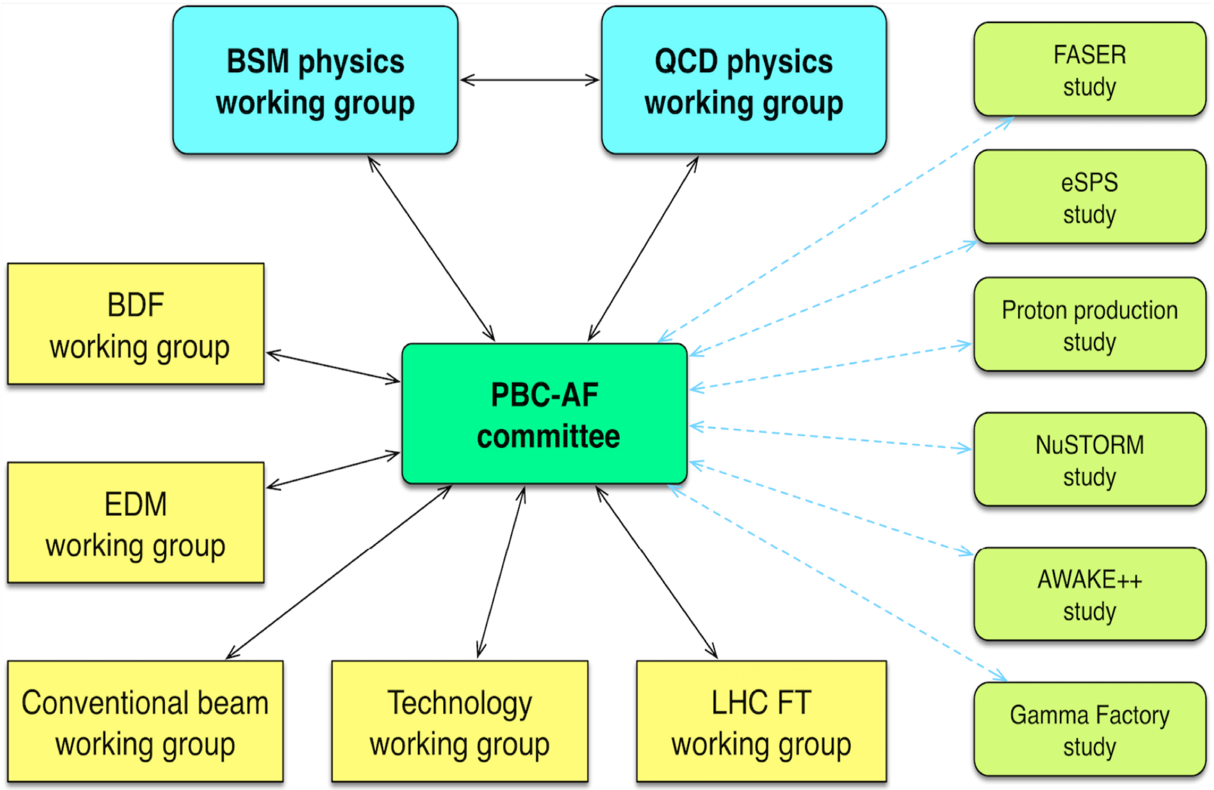
PBC mandate recently extended until the end of the ESPP, May 2020

Physics Beyond Colliders Structure



Evaluation of new proposals;
Optimization/upgrade of existing beam lines;
Technology support to proposals sited elsewhere;
Comprehensive Design Studies for mature projects

Physics Beyond Colliders Structure



Goals

- **Maximize performance of existing complex**
- **Harness existing expertise and resources**
- **New facilities exploiting existing complex**
- **Novel exploitation of existing facilities**

Physics Beyond Colliders: what CERN has got to offer?

- Existing accelerator complex and associated infrastructure
  - Wide range of beams, intensities, energies
- Technical expertise
  - Vacuum, magnets, power converters, RF, instrumentation, beam transfer, targets, cryogenics, accelerator physics, engineering…
- Experience
- Support
  - workshops, test facilities, engineering…
- Resources, size, and flexibility

PBC: documents as input to the ESPP

Overall executive summaries plus:

Physics:	
Beyond Standard Model WG	Physics cases and proposals
QCD WG	Physics cases and proposals
Accelerators and Tecnology:	
Protons post LIU	Evaluation and proposals
Technology	Evaluation and proposals
BDF	Comprehensive design study
Conventional beams	Case dependent feasibility studies
LHC FT	Preliminary conceptual designs
EDM	Feasibility study
Gamma factory	Exploratory study
AWAKE++	Exploratory study
nuSTORM	Exploratory study

← **Today's talk**

← **Next slide**

PBC: QCD physics programme

matrix of physics topics and proposals

	ALICE	LHCb SMOG2	LHC Spin	AFTER	COMPASS	MUonE	DIRAC++	NA60++	NA61++	crystals
unpolarised proton	x	x		x						
structure of nuclei	x	x		x						
polarised proton	x		x	x	x					
meson structure (π,K)					x					
heavy ion physics	x	x		x				x	x	
elastic μe or μp scattering					x	x				
spectroscopy, magn. moments					x					x
chiral dynamics					x		x			
measurements for cosmic rays		x			x				x	
measurements for neutrino ph.									x	

Extended presentation
at the PBC meeting in June by G. Schnell,
https://indico.cern.ch/event/706741/overview

The PBC(–BSM WG) mandate

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The PBC–BSM Working Group

Proposal	Representative
JURA	Axel Lindner
Codex-b	Michele Papucci
EDM ring	Yannis Semertzidis
FASER	Jonathan Feng
IAXO	Igor Irastorza
KLEVER	Cristina Lazzeroni
LDMX/eSPS	Philip Schuster
LHC-FT	Fernando Martinez-Vidal
LLP @ LHC	James Beacham
MATHUSLA	David Curtin
MilliQan	Albert de Roeck
NA62++	Tommaso Spadaro
NA64++	Sergei Gninenko
REDTOP	Isabel Pedraza
SHiP	Kostas Petridis
tauFV	Guy Wilkinson

**A lively community has born at CERN,
with about 15 different initiatives which could exploit
the CERN accelerator complex and scientific infrastructure
with a new, broad and compelling physics programme**

BSM WG Permanent Coordinators:
Clare Burrage (Nottingham U., UK)
Klaus Jungmann (Groningen U., The Netherland)
Klaus Kirch, PSI, Switzerland
Gaia Lanfranchi (INFN-LNF, Italy)
Maxim Pospelov (Victoria University, Canada)
Alexander Rozanov (CNRS, France)
Giuseppe Ruoso (INFN-Legnaro, Italy)

New Physics at the TeV scale?

"While the absence of NP appears as a paradox to us, still the picture repeatedly suggested by the data in the last 20 years is simple and clear:
the SM, extended to include some form of Dark Matter and Majorana's neutrinos, which can explain the active neutrino masses and oscillations via the see-saw mechanism and the **baryogenesis through leptogenesis, can be valid up to some very high energy, possibly up to the Planck scale**."

Guido Altarelli,
Proceedings of Vulcano Workshop 2014:
Frontier Objects in Astrophysics and Particle Physics

Fundamental Physics Questions

Experimental facts

1. Neutrino masses and oscillations

possible explanation: see-saw mechanism with RH neutrinos with Yukawa couplings to the Higgs and SM leptons. RH neutrinos can have masses from 10^{-9} to 10^{15} GeV.

2. Matter-antimatter asymmetry:

Requires a process in the very early universe which violates B-number conservation as well as C and CP symmetries and occurs out of equilibrium. In SM no enough CP violation or out-of equilibrium mechanism to explain it. Necessary new sources of CPV (eg: new phases in RH neutrinos).

3. Dark Matter:

SM Particles alone cannot account for the observed matter in the Universe.
DM candidates with mass from 10^{-31} GeV (ultralight scalars) to 10^{20} GeV (black holes) are viable.
The range for DM with thermal origin is more restricted (10 keV – 100 TeV).

Aesthetic arguments

Strong CP problem;

θ(QCD)~ 10^{-10}. Possible explanation: pseudo-Nambu Goldstone bosons associated to the Peccei-Quinn symmetry, the axion. Oscillating axion can be a DM candidate.

EDMs and New sources of CPV:

EDMs are excellent probes of sources of CPV beyond the SM

Higgs mass stability against radiative corrections (fine tuning):

if there is an intermediate scale between EW and Planck scales then NP at the TeV scale is required. Search for NP in extremely rare processes.

PBC-BSM: Physics Motivations

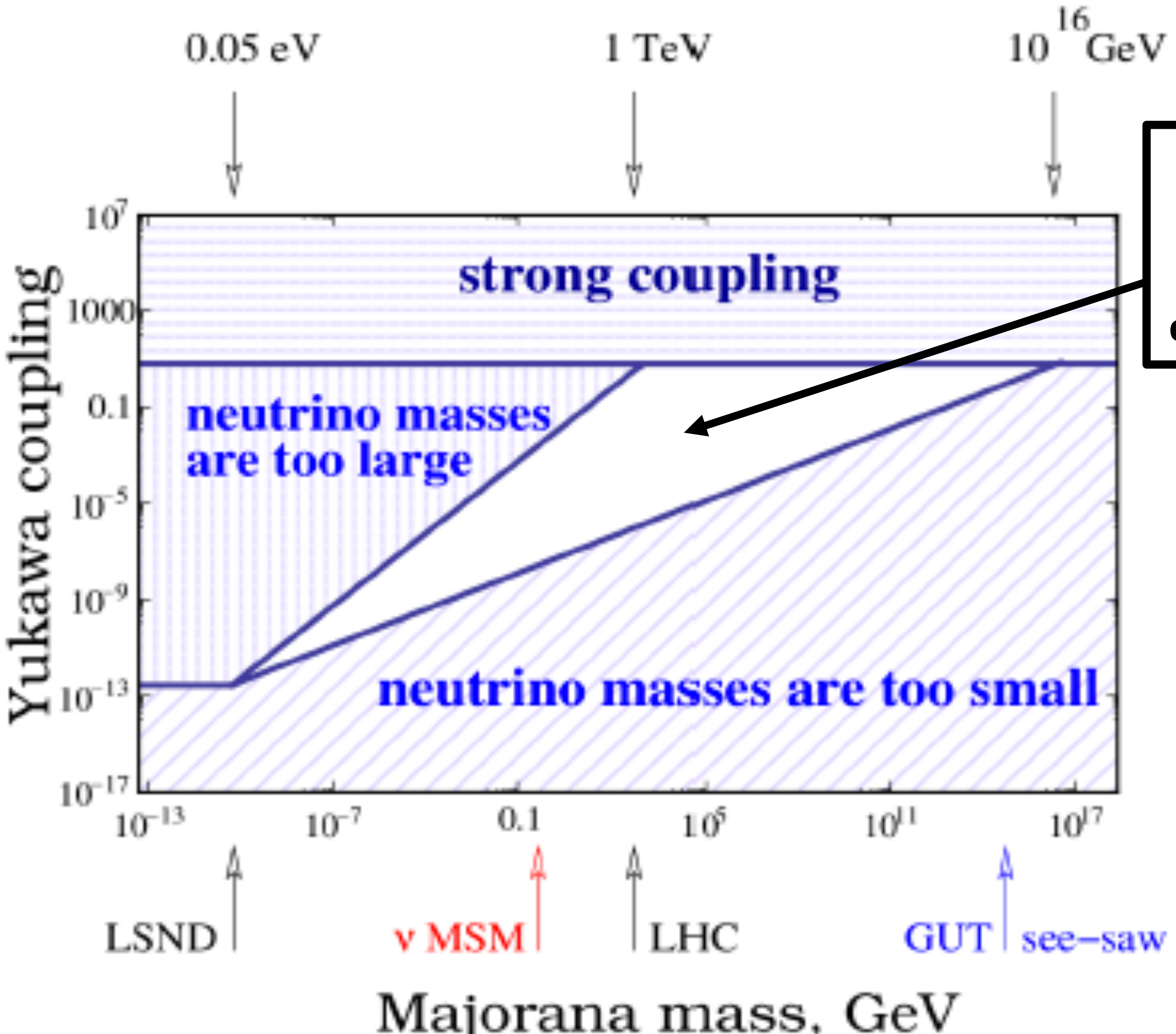
❑ So far the experimental efforts in the accelerators' domain have been concentrated on the discovery of New Particles with masses at the TeV scale (or above) and sizeable couplings to SM particles.

❑ We did not observe so far unambiguous deviations from SM predictions, hence:
→ either NP is very heavy and/or it mimics the SM in its flavor-breaking pattern or
→ **it is below the Fermi scale and couples very feebly to SM particles and so far escaped detection. This is the target of most of the projects of the PBC-BSM.**

A change of paradigm in accelerator physics.

1) RH neutrinos as explanation of the neutrino masses and oscillations

See-saw mechanism with RH neutrinos with Yukawa couplings to the Higgs and SM leptons. RH neutrinos can have masses from 10^{-9} to 10^{15} GeV.



Any number in the white area works to be consistent with the observed pattern of neutrino masses and oscillations

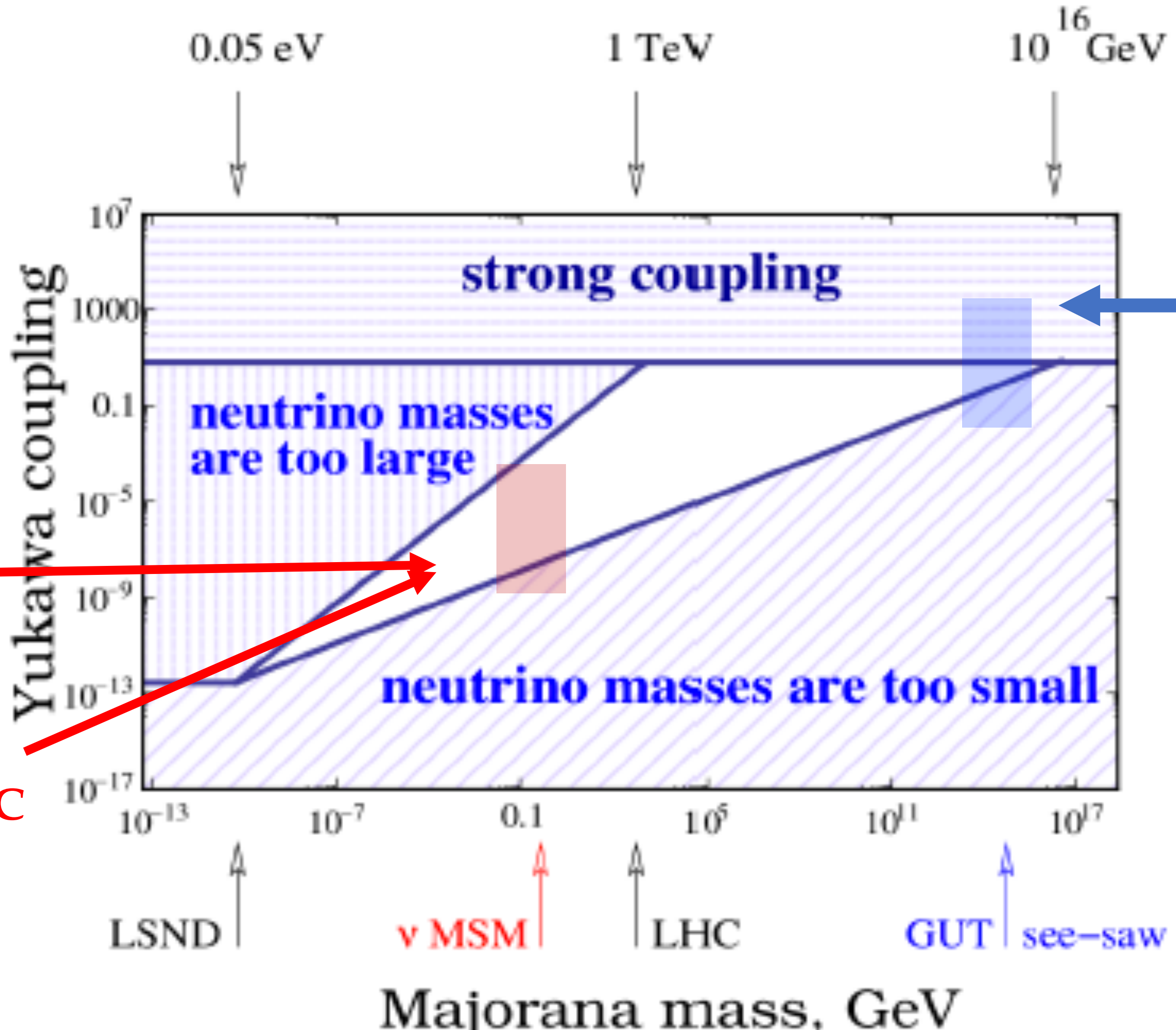
1) RH neutrinos as explanation of the neutrino masses and oscillations

See-saw mechanism with RH neutrinos with Yukawa couplings to the Higgs and SM leptons. RH neutrinos can have masses from 10^{-9} to 10^{15} GeV.

Alternative choice: EW see-saw (νMSM)

It is "natural" to assume that the masses of the RH neutrinos are at EW scale

Range of interest of PBC

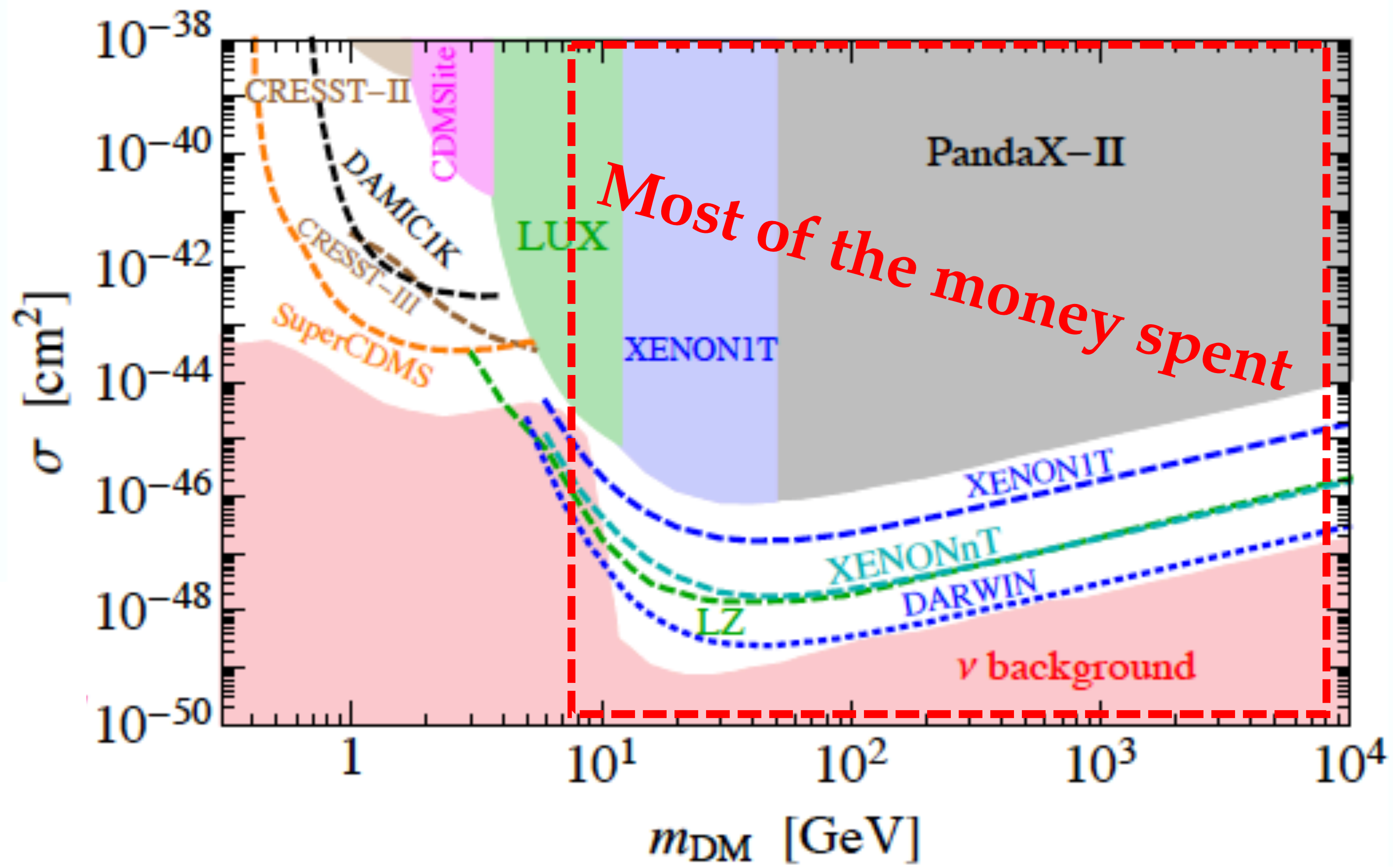


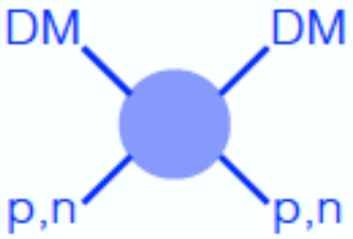
Popular choice: GUT see-saw

It "natural" to assume that Yukawa couplings of the RH neutrinos are similar to SM Yukawa.

2) Search for Dark Matter with thermal origin

DM candidates with thermal origin can have mass between 10 keV and 100 TeV.





< 10 keV
DM too hot, spoils structure formation

~ m_e — **1 MeV**

~ m_p, m_n — **1 GeV**

WIMPs paradigm — **M_Z**

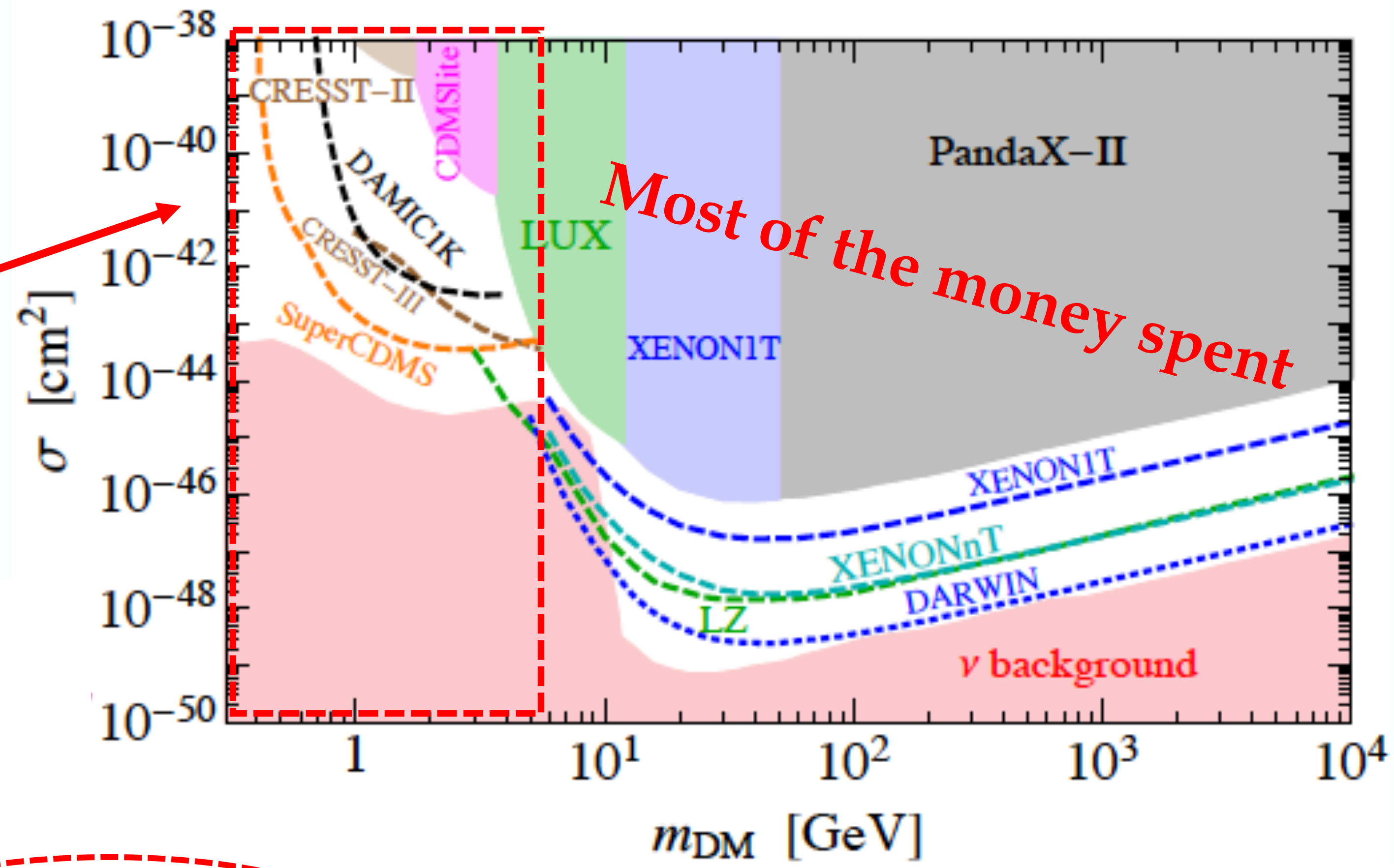
10 TeV

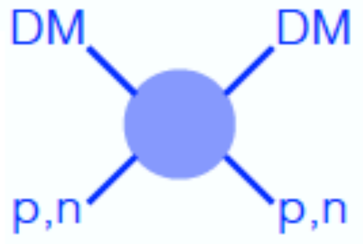
> 100 TeV
DM overproduced

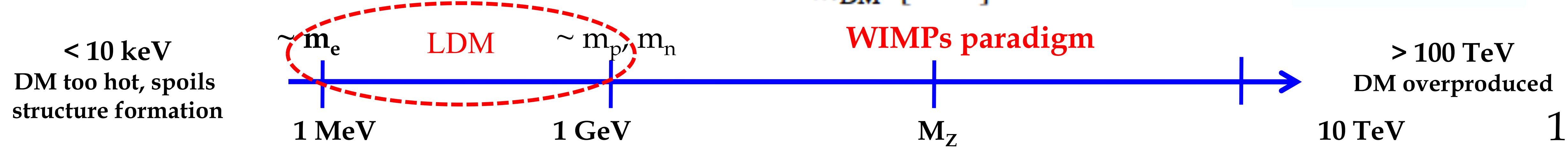
2) Search for Dark Matter with thermal origin

DM candidates with thermal origin can have mass between 10 keV and 100 TeV.

Range of interest of the PBC - BSM







PBC-BSM: physics targets

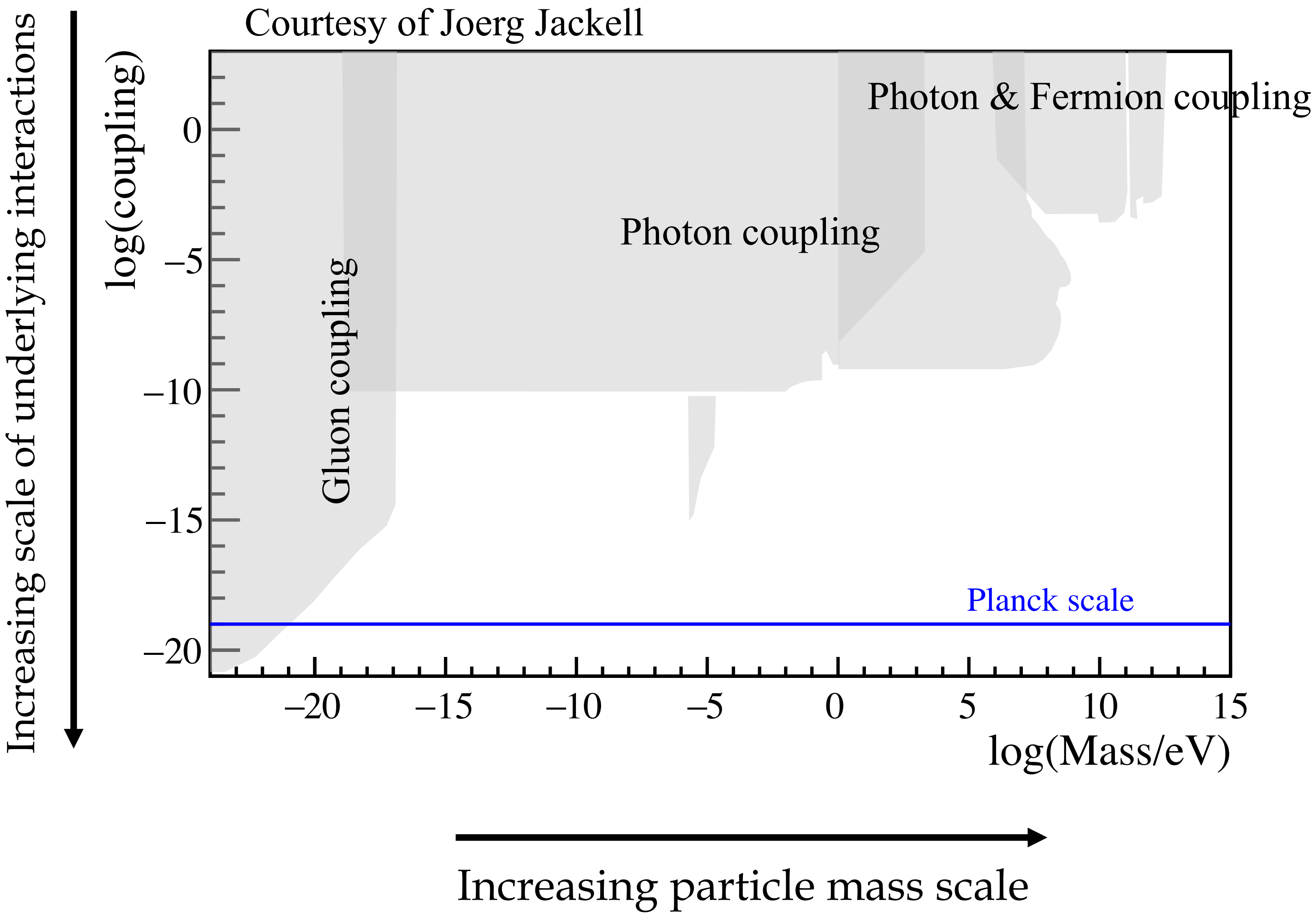
Light thermal DM and corresponding light mediators, RH neutrinos at the GeV scale,
Axions and axion-like particles, EDM in proton/deuteron and in long-lived charmed hadrons;
Ultra-TeV New Physics in extremely rare processes.

Light mediators must be SM singlets, hence options limited by SM gauge invariance:

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	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu} \tilde{G}^{\mu\nu}_i$, $\frac{\delta_\mu a}{f_a} \overline{\psi} \gamma^\mu \gamma^5 \psi$
Sterile Neutrino, N	$y_N L H N$

This is the set of the simplest fields and renormalizable interactions that can be added to the SM to answer the three fundamental questions.

Starting to quantify a comprehensive picture



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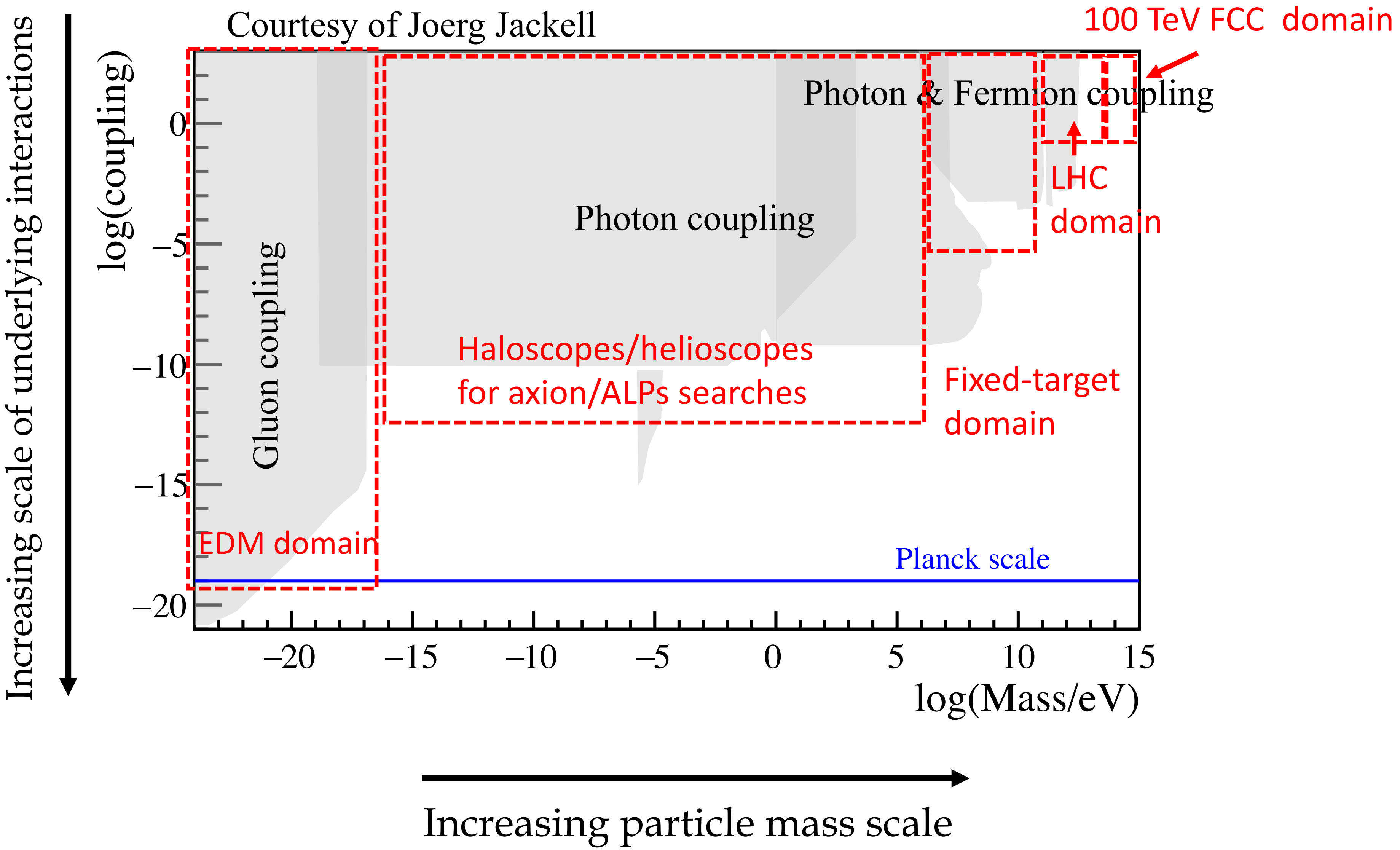


Physics Beyond Colliders: BSM experimental programme

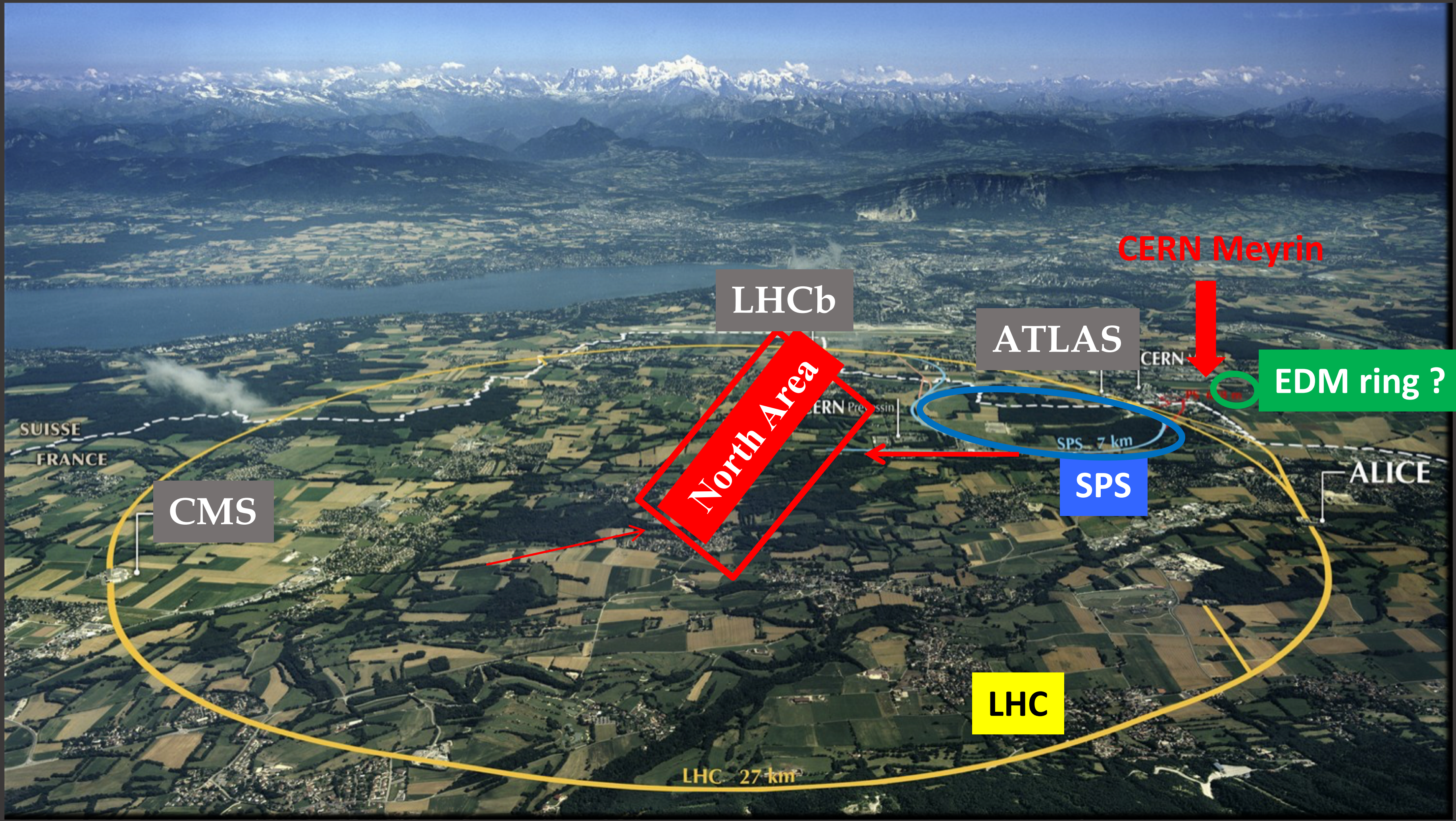
The projects considered in the BSM WG have been classified in the terms of sensitivity to benchmark cases in a given mass range. Since the TeV scale is very well explored at the LHC, we focus on:

sub-eV range: search for axions, Axion-like particles with:
- gluon coupling: protons and deuteron EDMs or in charmed baryons MDMs/EDMs
- photon coupling with axion helioscopes or laboratory experiments (LSW).

MeV-GeV range: search for RH neutrinos below the EW scale, Axion-Like Particles, Light Dark Matter and corresponding light mediators (Dark Photons, Dark Scalars, etc) at extracted beams or at the LHC interaction points.

>>TeV range:
Search for NP in clean and very rare or forbidden flavor processes or in EDMs as probe of > 100 TeV NP scales, if originated by new sources of CPV.

The CERN Accelerator Complex and Sites



The PBC Focus in on “beyond colliders” activities, but the community is larger and includes also projects that exploit the LHC interaction points.

Projects considered in the BSM WG

Proposal	physics case	beam line	beam type	beam yield
sub-eV range:				
IAXO	axions/ALPs (photon coupling)	–	axions from sun	–
ALPS-III	axions/ALPs (photon coupling)	laboratory	LSW	–
CPEDM	p, d EDM,	EDM ring	p, d	–
	axions/ALPs (gluon coupling)		p, d	–
LHC-FT	charmed hadrons MDMs, EDMs	LHCb IP	7 TeV p	–
MeV-GeV range:				
SHiP	ALPs, Dark Photons,	BDF	400 GeV p	$2 \cdot 10^{20}$/5 years
	Dark Scalars, LDM, HNLs			
NA62^{++}	ALPs (photon, fermion coupling)	K12	400 GeV p	up to $3 \cdot 10^{18}$/year
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NA64^{++}	ALPs (which couplings?)	H4	100 GeV e^-	$5 \cdot 10^{12}$ eot/year
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	$+ L_\mu - L_\tau$	M2	160 GeV μ	$10^{12} - 10^{13}$ mot/year
	+ CP, CPT, leptophobic DM	H2-H8, T9	$\sim$ 40 GeV π, K, p	$5 \cdot 10^{12}$/year
LDMX	Dark Photon, LDM, ALPs,...	eSPS	8 (SLAC) -16 (eSPS) GeV e^-	$10^{16} - 10^{18}$ eot/year
RedTop	Dark Photon, Dark scalar	CERN PS	1.8 or 3.5 GeV	10^{17} pot
MATHUSLA	Dark Scalar, Dark Photon, HNLs,..	ATLAS or CMS IP	14 TeV p	3000 fb^{-1}
FASER	Dark Photon, Dark Scalar, ALPs	ATLAS IP	14 TeV p	3000 fb^{-1}
MilliQan	milli charge	CMS IP	14 TeV p	300-3000 fb^{-1}
Codex-b	Dark Scalar, Dark Photons, ...	LHCb IP	14 TeV p	300 fb^{-1}
> TeV range:				
KLEVER	$K_L \to \pi^0 \nu \bar{\nu}$	P42	400 GeV p	$5 \cdot 10^{19}$ pot /5 years
TauFV	LFV τ decays	BDF	400 GeV p	5% of the SHiP yield

Projects considered in the BSM WG: sub-eV range

Dark sector in the sub-eV range:

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Proton and Deuteron EDMs:

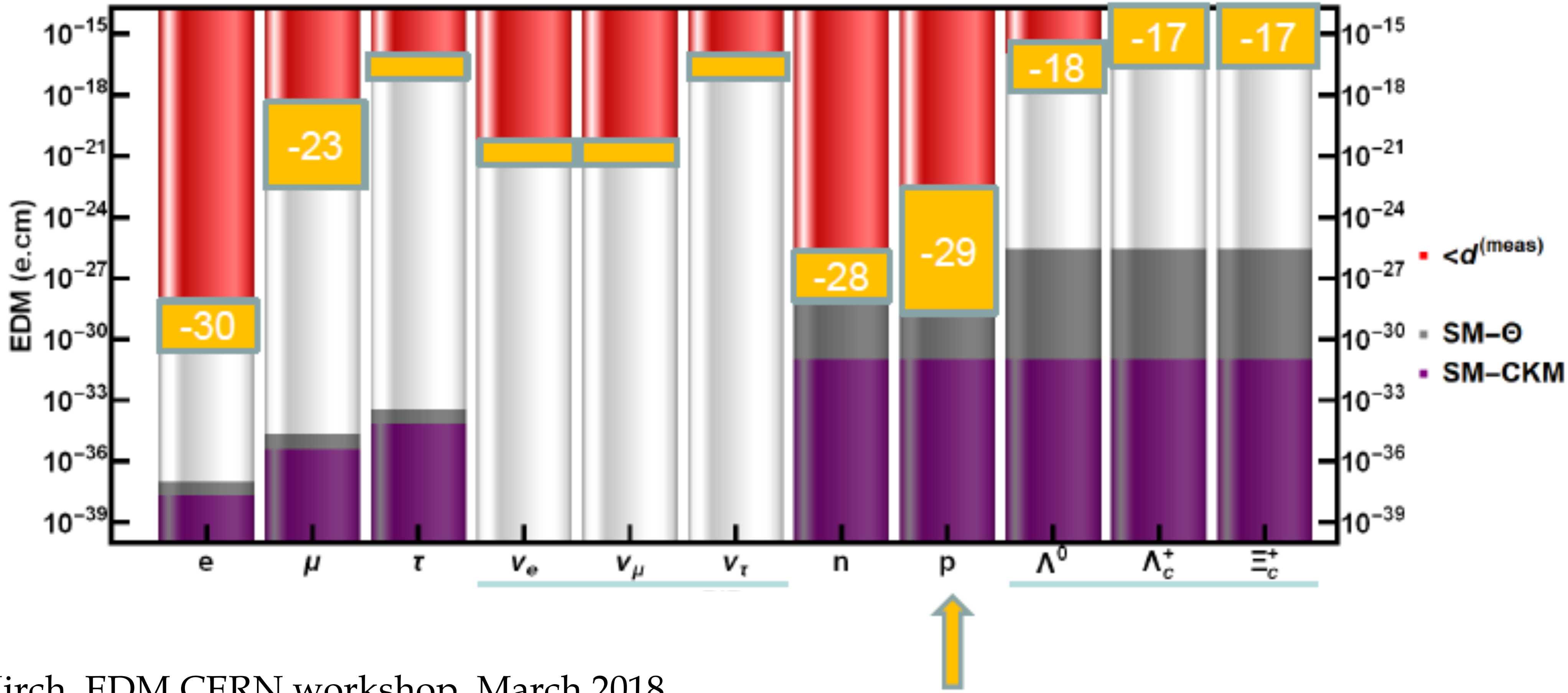
search for new sources of CPV in the sub-eV (axion) or multi TeV scales

<u>Possible site:</u> fully electrostatic ring can fit into the ISR ring, Meyrin area

Proton and Deuteron EDMs:
search for new sources of CPV in the sub-eV (axion) or multi TeV scales

Good collaboration established with IKP in Juelich, KAIST in South Korea.
Now pushing a small scale prototype ring (technology, systematics etc.)
as a staged approach towards a full scaled ring.
Possible siting of prototype in Juelich (site of COSY).
Systematics recognised to be very challenging.

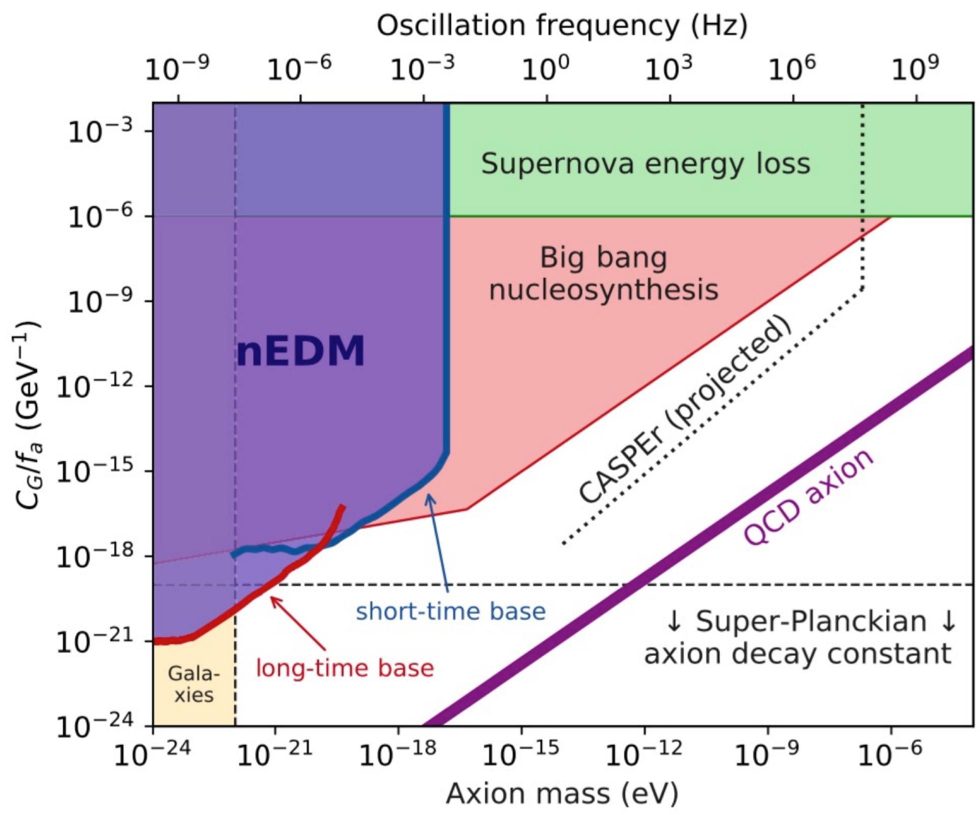
Next future 2020s perspectives



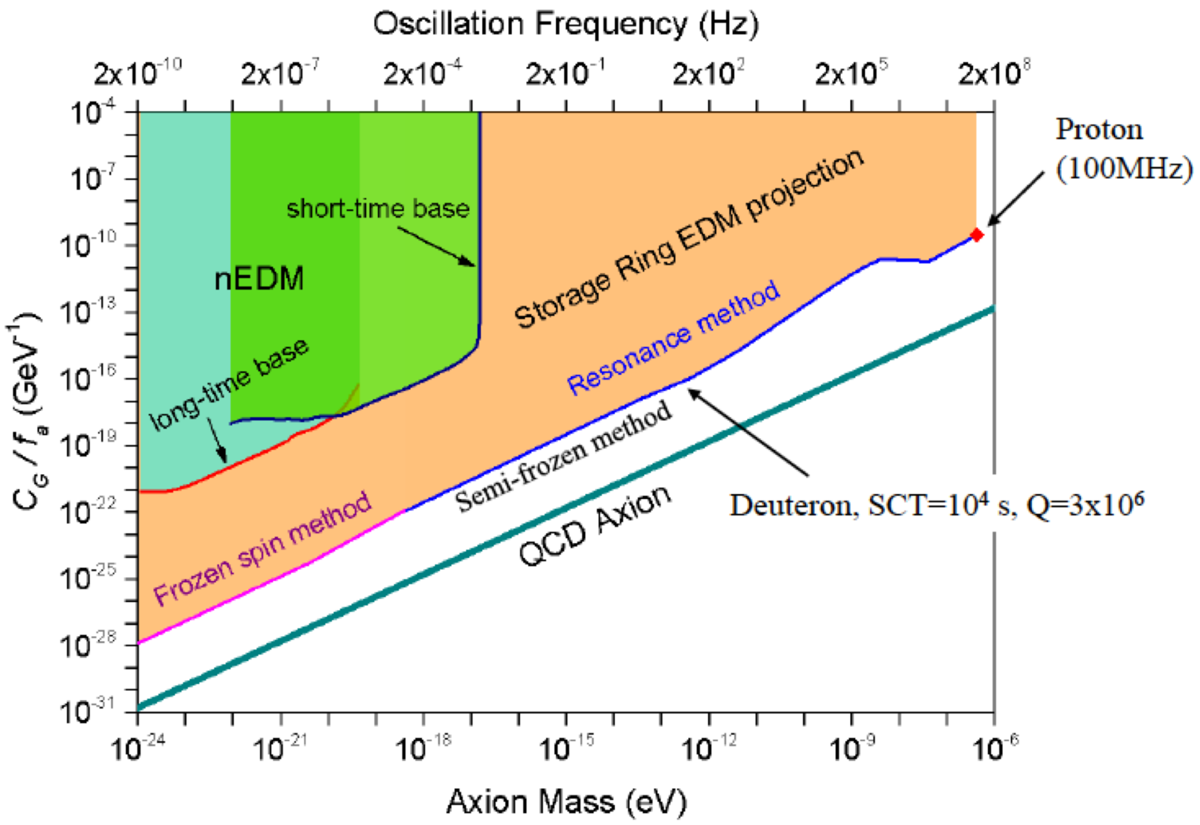
K. Kirch, EDM CERN workshop, March 2018

Target of the PBC

If the EDMs in proton, deuteron are generated by oscillating axions search for EDMs → search for axions.



PHYSICAL REVIEW X 7, 041034 (2017)

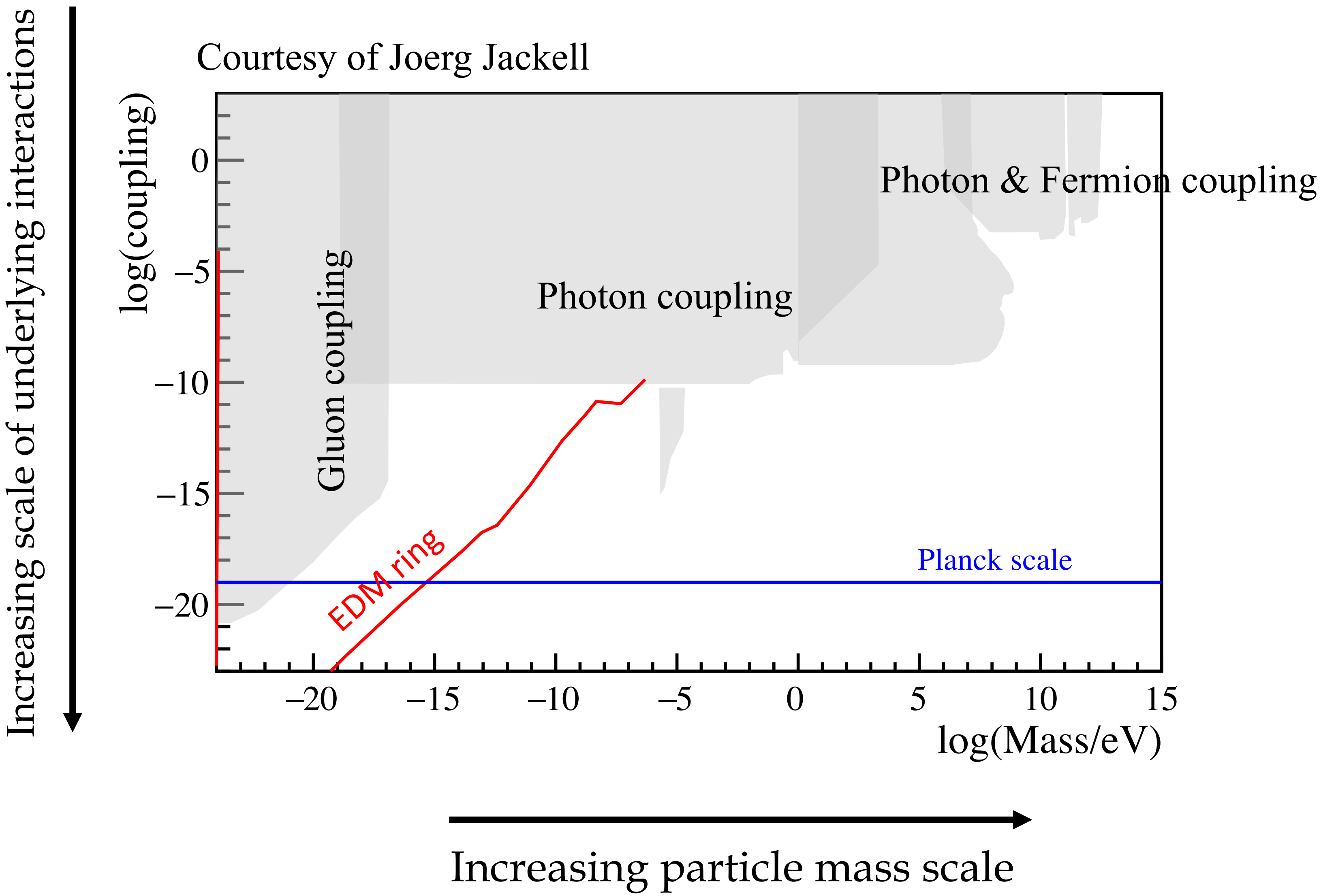


Y. Semerztidis, EDM workshop, CERN March 2018

Interpretation of results is controversial because exclusion limits are strictly valid only for axions: they can be interpreted either as **sensitivity plots or as exclusion plots of more complicated (controversial) models**

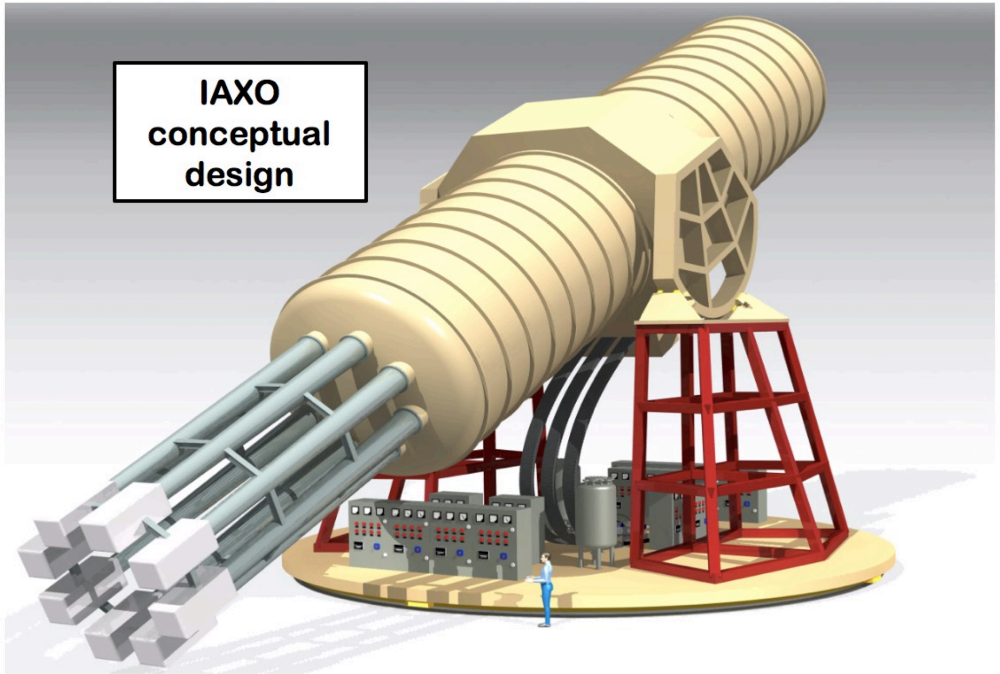
Starting to quantify a comprehensive picture

Courtesy of Joerg Jackell



The International Axion Observatory (IAXO) Project

- Next generation "axion helioscope" after CAST
- Purpose-built large-scale magnet
  - >300 times larger B^2L^2A than CAST magnet
  - Toroid geometry
  - 8 conversion bores of 60 cm Ø, ~20 m long
- Detection systems (XRT+detectors)
  - Scaled-up versions based on experience in CAST
  - Low-background techniques for detectors
  - Optics based on slumped-glass technique used in NuStar
- ~50% Sun-tracking time
- Large magnetic volume available for additional "axion" physics (e.g. DM setups)



17 Institutions already joined the project. Strong interest of DESY to host it.
Magnet under design with strong CERN support.

IAXO and ALPS-III (now called JURA) and other smaller experiments are considered in the Technology Group

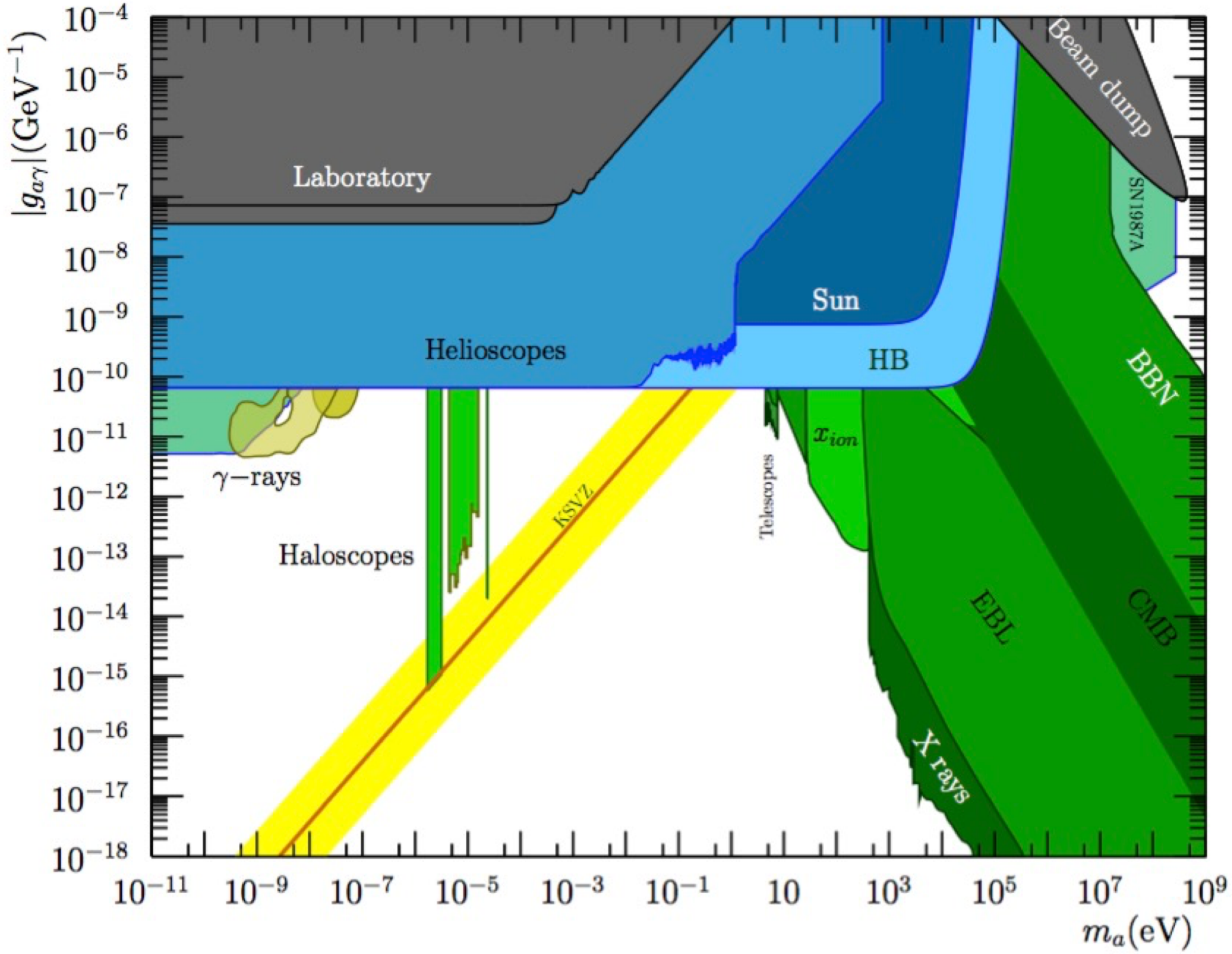
Technology WG

Technology contribution of/to CERN	Initiatives concerned
Magnet, concretely: high-field, large-bore	IAXO, OSQAR+, ALPS-III, STAX, OSQAR-PVLAS-VMB
Optics/Optics sensing, e.g.: Fabry Perot, membranes, cooling mirrors	OSQAR-PVLAS-VMB, ALPS-III, OSQAR+, aKWISP
RadioFrequency cavities, concretely: design for axion searches	Grenoble initiative, & other Haloscope initiatives operating already at CERN, STAX
Cryogenics, e.g.: helium, argon, krypton from 120K to mK	DarkSide, aKWISP, OSQAR-PVLAS-VMB, IAXO
Vacuum group, e.g.: large-scale leak testing + surface technology	DarkSide, OSQAR+, aKWISP, Nanotubes

- High Field Magnets
- Optics/optics sensing
- RF cavities
- Cryogenics
- Vacuum

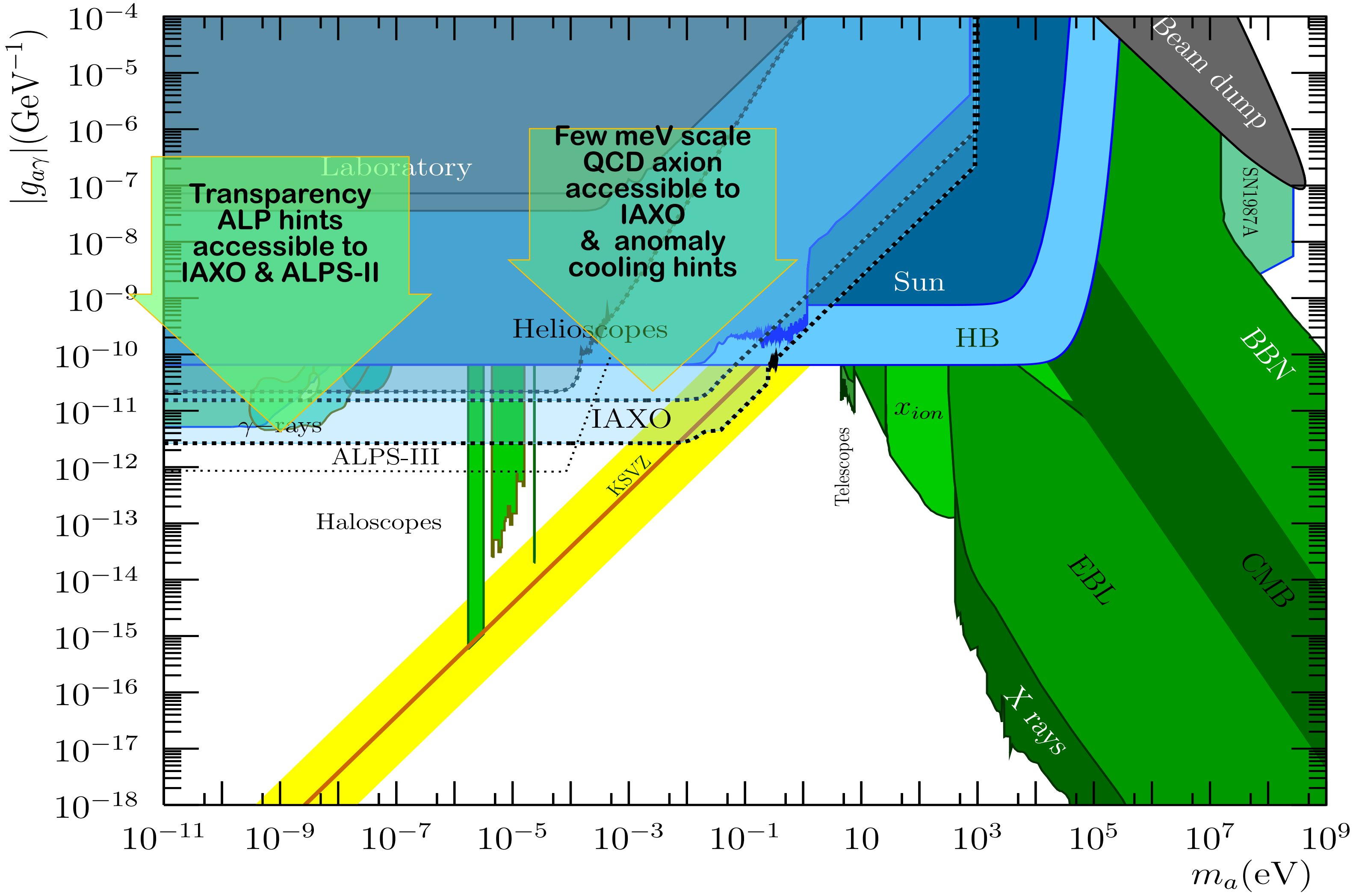
~ 100 pp Report in preparation for the ESPP

Axions and ALPs with photon coupling in the sub-eV mass range: Worldwide Landscape

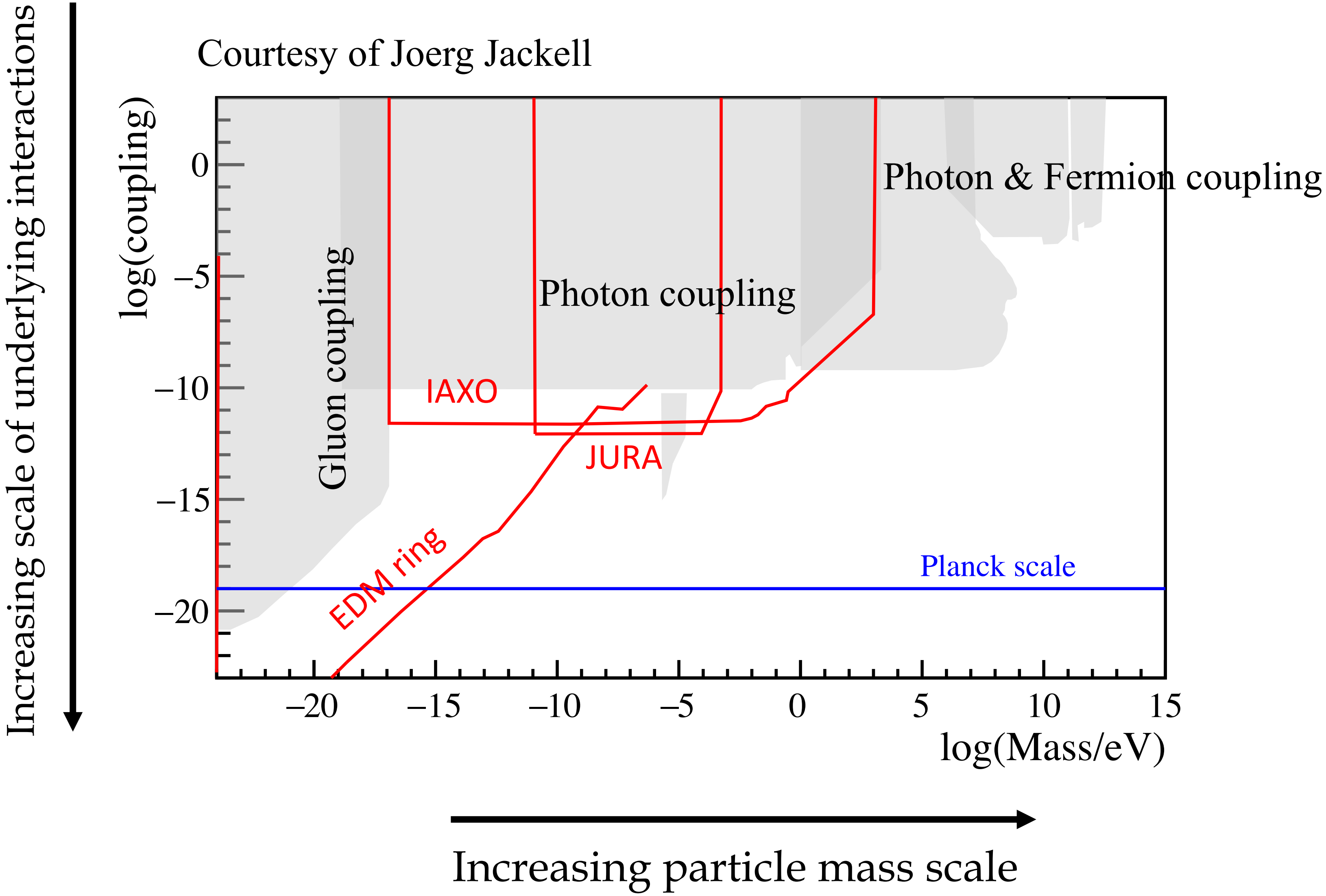


arXiv:1801.08127

Axions and ALPS with photon coupling in the sub-eV mass range
PBC projects: IAXO and Jura (ex ALPS-III)



Starting to quantify a comprehensive picture



Projects considered in the BSM WG: MeV-GeV range

Dark sector in the MeV-GeV range:

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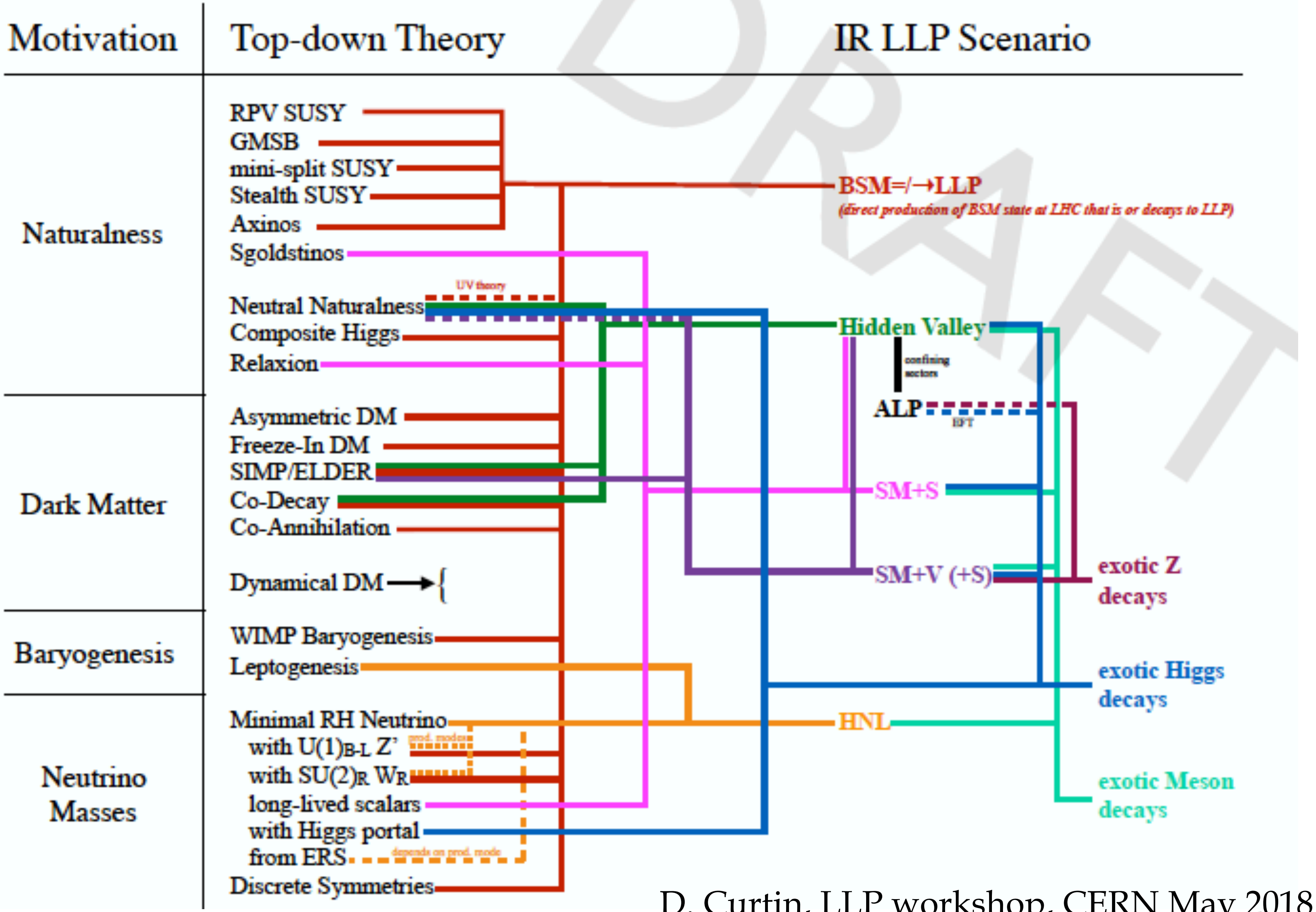
@ SPS

@ PS

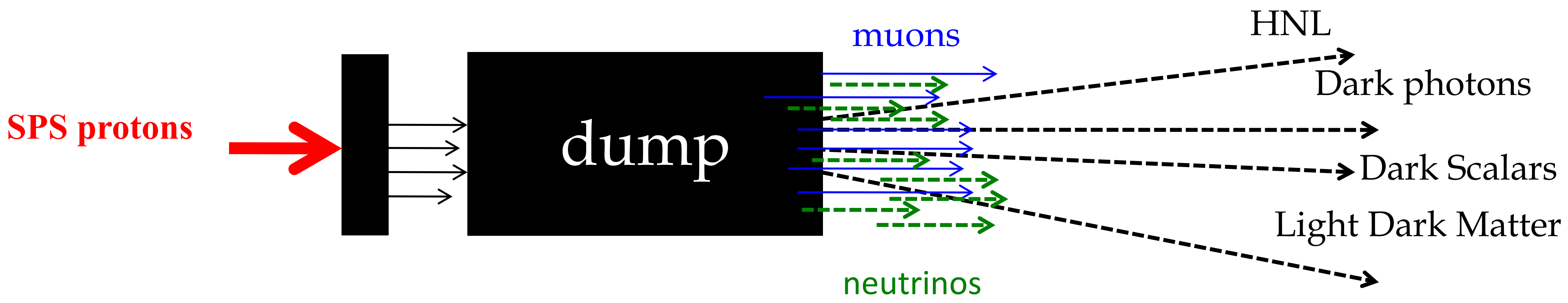
@ LHC

Several reasons to search for generic weakly-interacting long lived particles



D. Curtin, LLP workshop, CERN May 2018

Search for long-lived particles in the MeV-GeV range with “DUMP” experiments

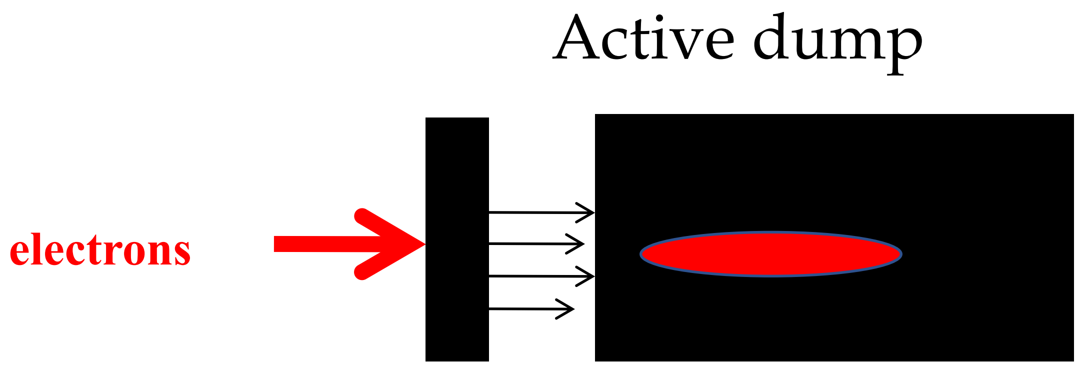


Technique used by NA62^{++}, SHiP, NA64^{++}
(and indirectly also by MATHUSLA, FASER, CodexB, MilliQan)

(RedTop uses narrow η, η' resonances to search Hidden Particles in visible final states)

Search for long-lived particles in the MeV-GeV range: "ACTIVE DUMP" experiments

Any discrepancy between the energy of the electron measured before and in the active dump would be sign of the production of some non-interacting particles, as for example Dark Matter

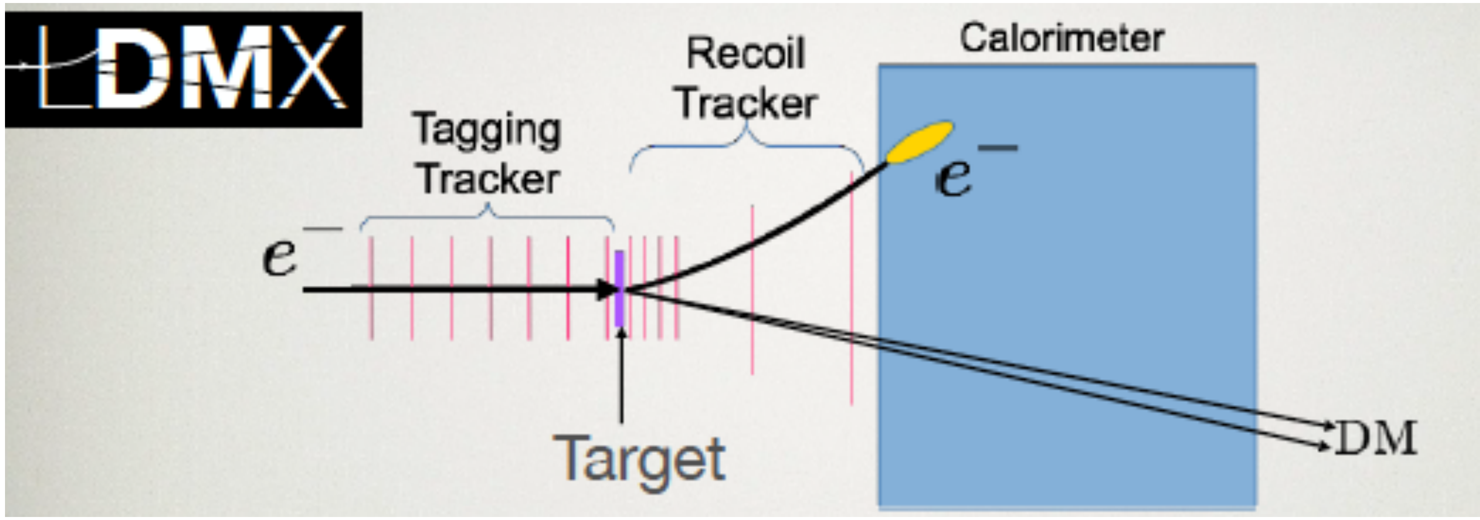


Missing Energy technique mainly used by NA64++

Search for long-lived particles in the MeV-GeV range : “MISSING MOMENTUM” technique

Missing momentum:

any discrepancy between the momentum of the electron/muon measured before and after the target would be sign of the production of some non-interacting particle, as for example Dark Matter



Missing momentum technique mostly used by LDMX @ eSPS

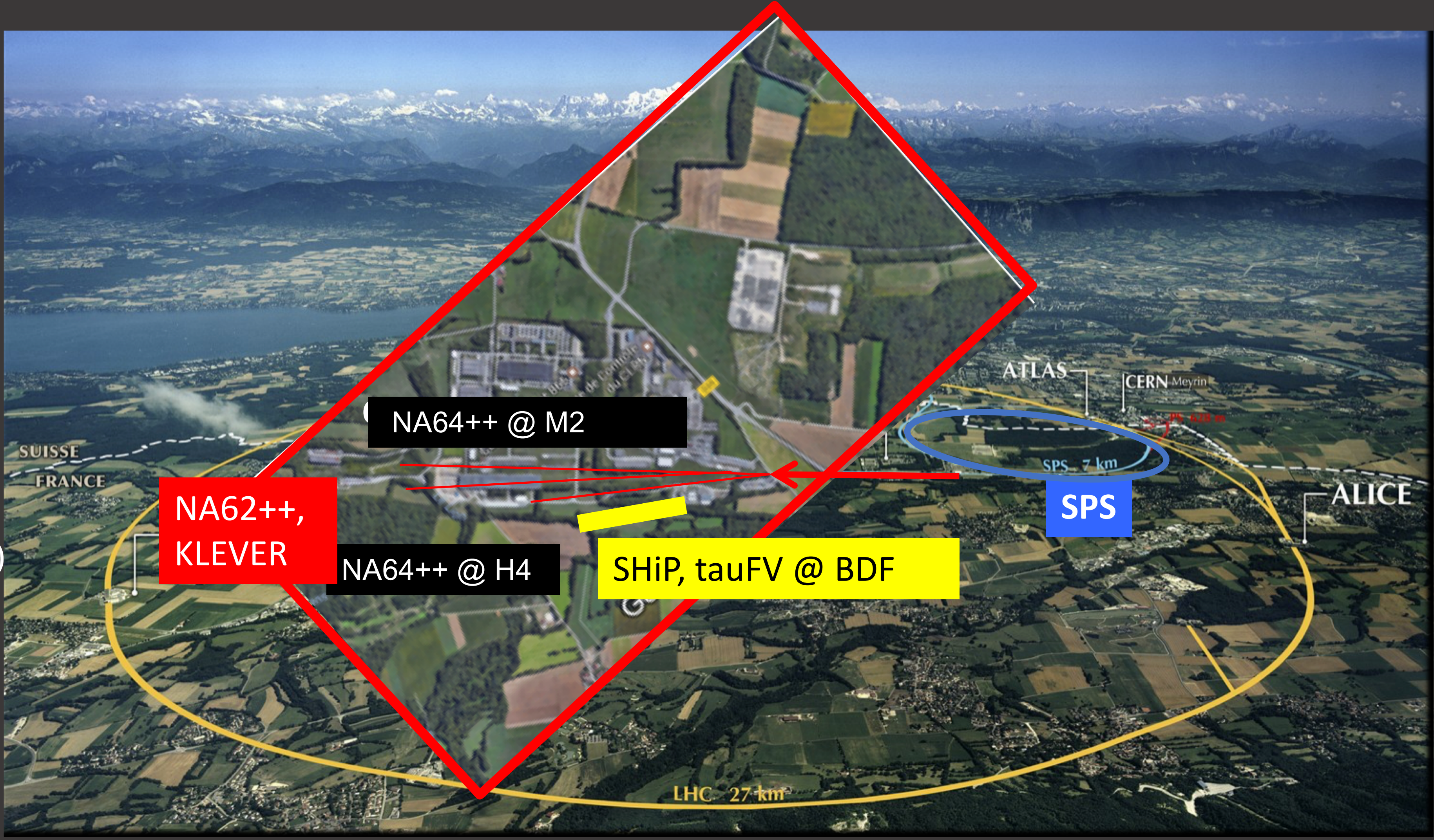
Beam lines available/proposed in the North Area

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

H4: **100 GeV e- beam**
up to 5×10^{12} eot/year
→ **NA64⁺⁺ (electrons)**

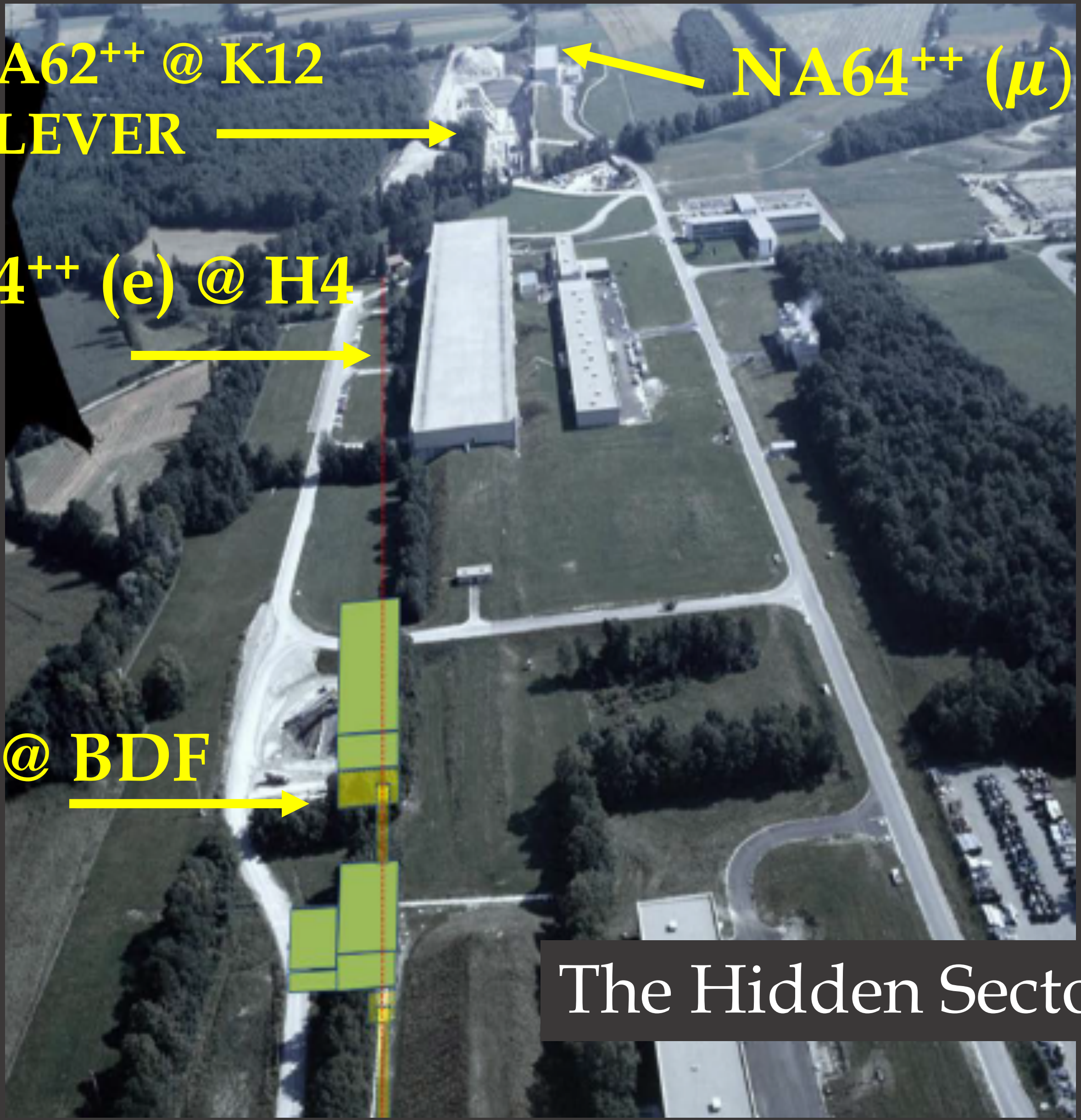
K12: **400 GeV p beam**
up to 3×10^{18} pot/year (now)
→ **NA62⁺⁺ (NA62-dump)**
up to 10^{19} pot/year (if upgraded)
→ **KLEVER**

BDF (proposed): **400 GeV p**
up to 4×10^{19} pot/year
→ **SHiP, TauFV**



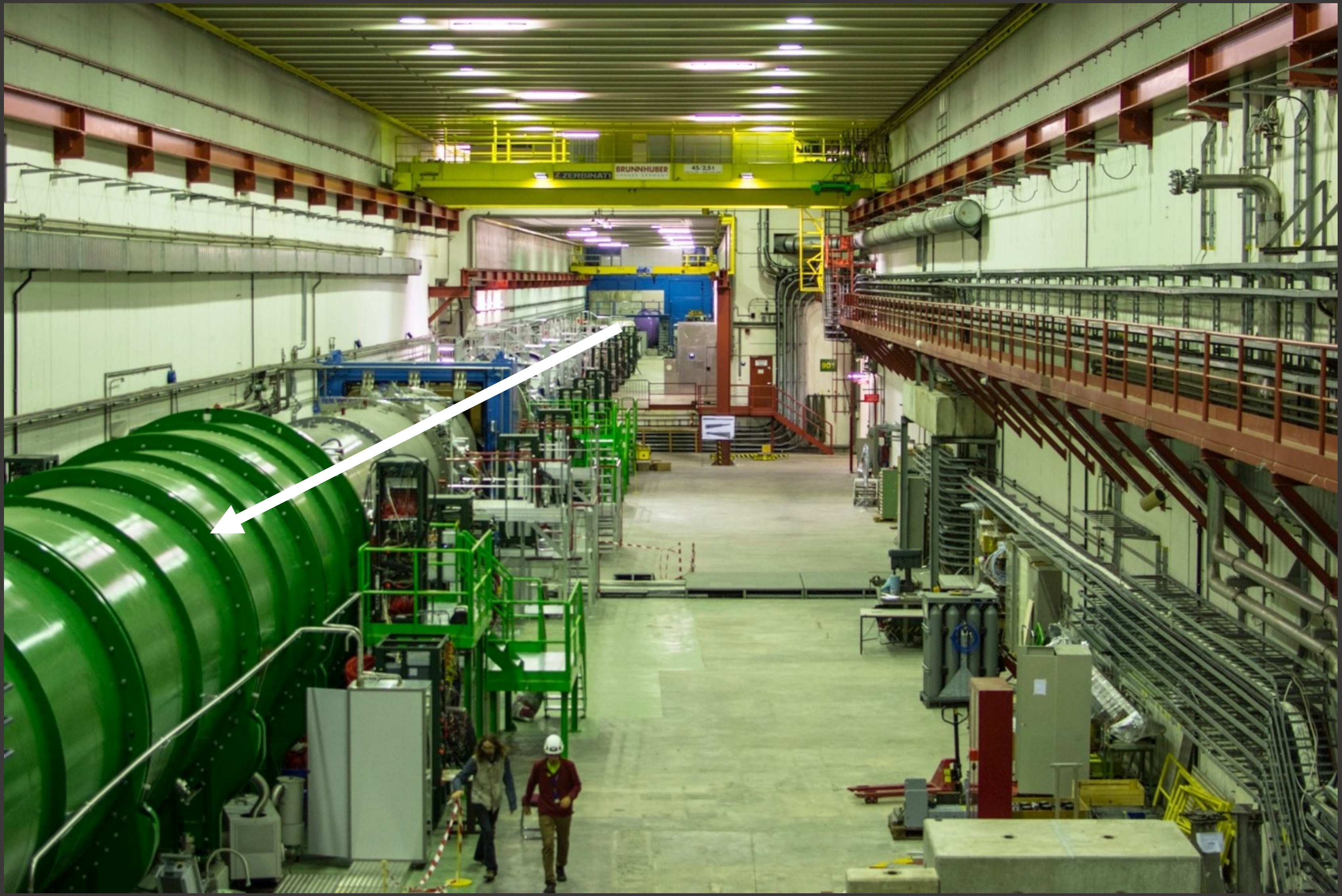
Highest energy proton, electrons and muon beams delivered for fixed target experiments in the world.

Aerial picture of the North Area



The NA62 experiment @ K12 in EHN3

https://na62.web.cern.ch/

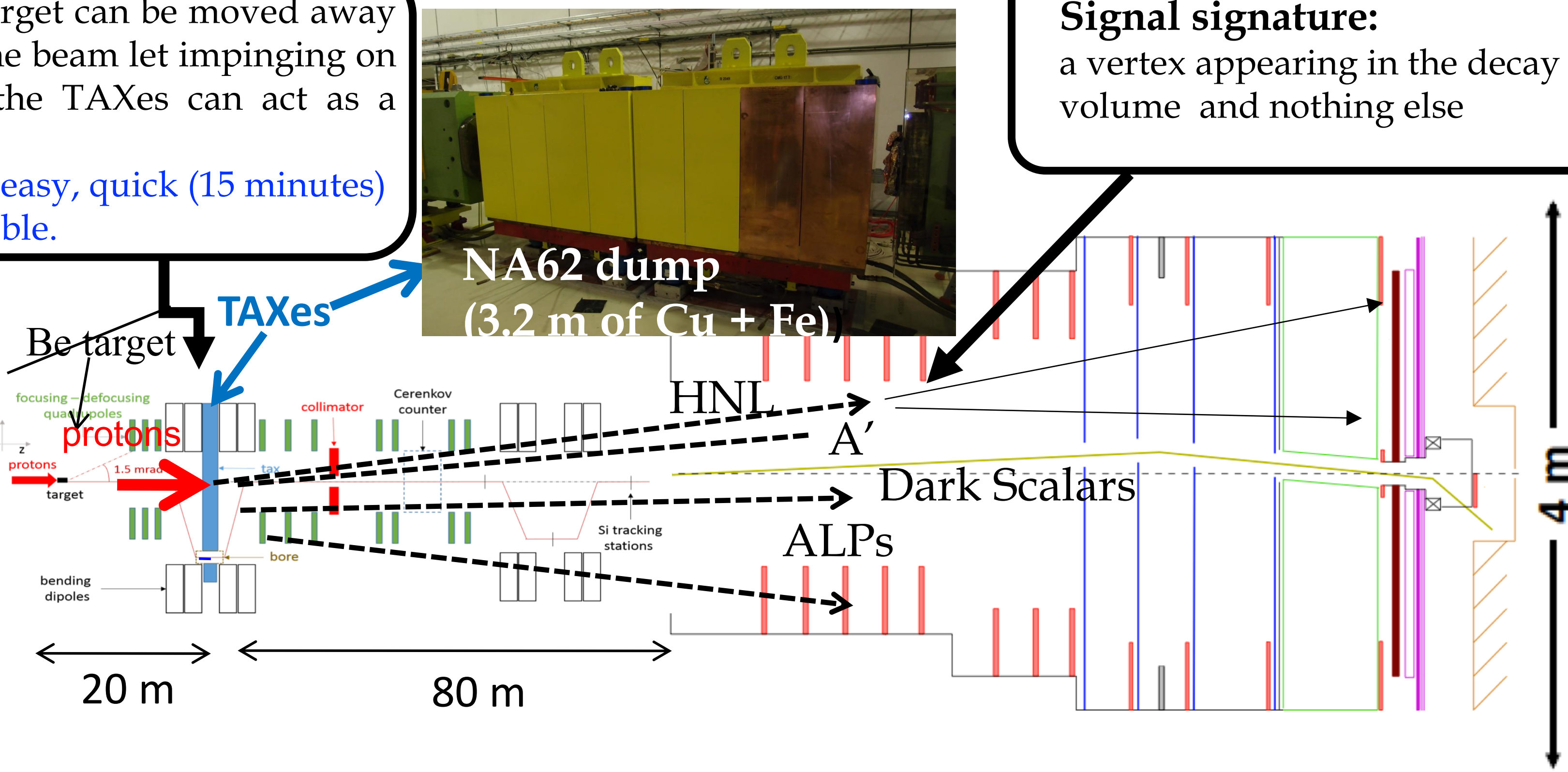


NA62 in "dump" mode (2023++)

NA62 currently running in K12. Will complete the kaon programme by 2022.
Proposed o(1) year in dump mode by 2023.

In dump mode the target can be moved away from the beam and the beam let impinging on the copper. Hence: the TAXes can act as a dump (2x10.7 λ_I).
⟶ this operation is easy, quick (15 minutes) and fully reversible.

Signal signature:
a vertex appearing in the decay volume and nothing else



**Optimization of the beam line studied in the Conventional Beams WG
(L. Gatignon et al., ~100 pp Yellow Report in preparation for the ESPP)**

NA62 in dump mode: scientific scheduling

NA62 has the main goal of measuring the BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) with 10% accuracy;

- **Before LS2 (2017-2018)** many searches in the hidden sector will be performed using the kaon beam.
- **After LS2 (2021++)** there is a window of opportunity to run NA62 in beam-dump mode to collect at least 10^{18} pot to search for hidden particles from charm and beauty decays, and photons.

today

LS2

LS3

NA62: $K^+ \rightarrow \pi^+ \nu \nu$, LFV/LFU modes
Hidden sector from K decays

NA62 in dump mode
and kaon physics

SHiP, MATHUSLA, Codex-b, FASER, DUNE, etc.

Goal: integrate at least ~10^{18} pot in dump mode by 2023
(corresponding to ~ 3 months of dedicated data taking in 2021-2023)

The NA64 experiment in EHN1, H4

https://na64.web.cern.ch/

NA64 has been approved in March’16 for dark photon to invisible searches with 100 GeV e^- beam;
Current status: running @ H4; collected o(10^{11}) eot.

NA64^{++}: electrons, muons and hadrons

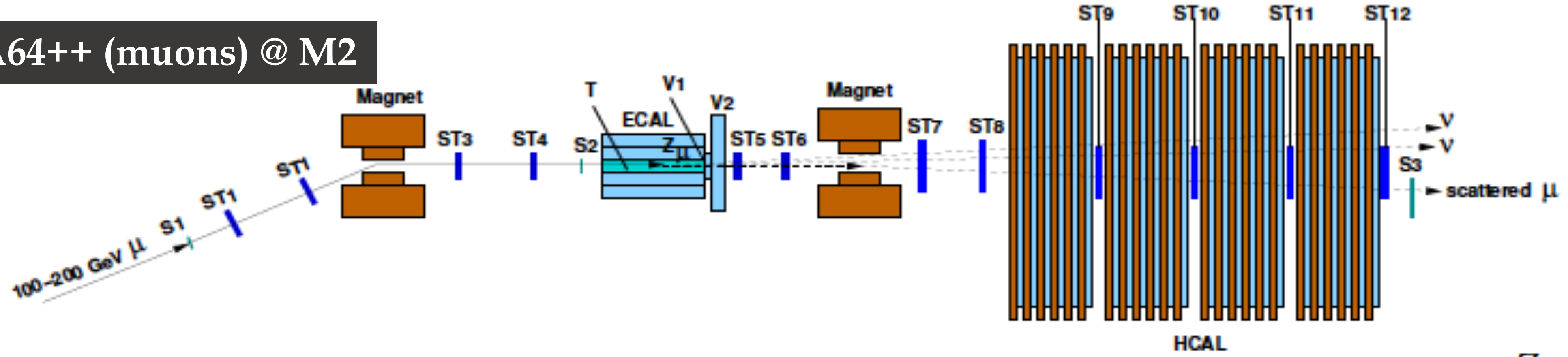
Proposal to extend the physics programme after LS2:

NA64++ (electrons): extension beyond 2021 to accumulate up to 5×10^{12} eot in H4

NA64++ (muons): use the 100-160 GeV muon beam in COMPASS area to study hidden sector with muon couplings. Very complementary to Dark Sector with electron couplings. Integration with COMPASS experiment under study. Preliminary test done in 2017 with the COMPASS setup show that the purity of the muon can be kept under control. Interplay between NA64, COMPASS and MUonE under study.

NA64++ ($K_{L,S}$, $\pi^0, \eta, \eta' \rightarrow$ invisible): produced via charge exchange reactions $\pi(K)\ p \rightarrow M^0\ n + E_{miss}$

NA64++ (muons) @ M2



Eg: search for a Z_μ in the bremsstrahlung reaction: $\mu + Z \rightarrow \mu + Z + Z_\mu$

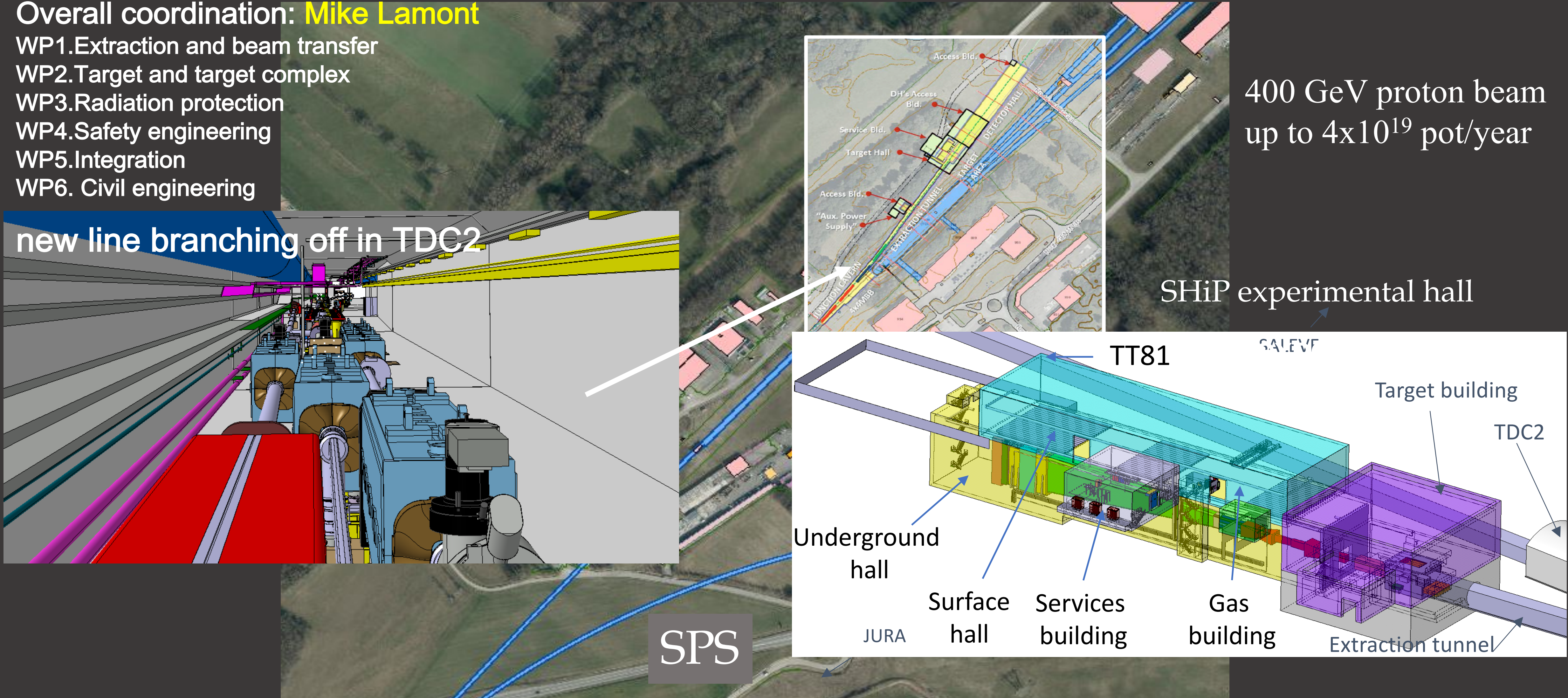
Optimization of the beam line studied in the Conventional Beams WG (~100 pp Yellow Report in preparation for the ESPP)

A Z_μ model gauging the $L_\mu - L_\tau$ lepton number can explain the LFU violations in R_K and R_{K^*}

Beam Dump Facility (BDF) in the North Area

Overall coordination: Mike Lamont

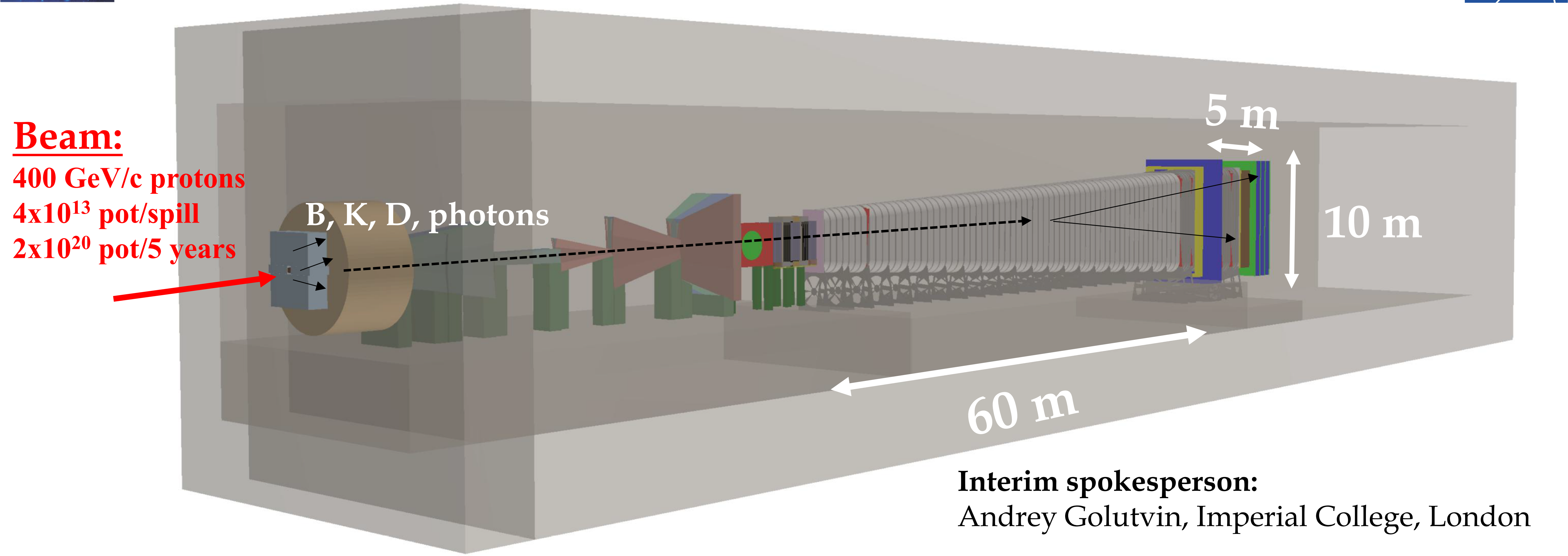
- WP1.Extraction and beam transfer
- WP2.Target and target complex
- WP3.Radiation protection
- WP4.Safety engineering
- WP5.Integration
- WP6. Civil engineering



400 GeV proton beam
up to 4×10^{19} pot/year

3.7 MCHF already allocated by CERN for feasibility studies
~300 pp Yellow Report in preparation for the ESPP

SHiP project @ BDF



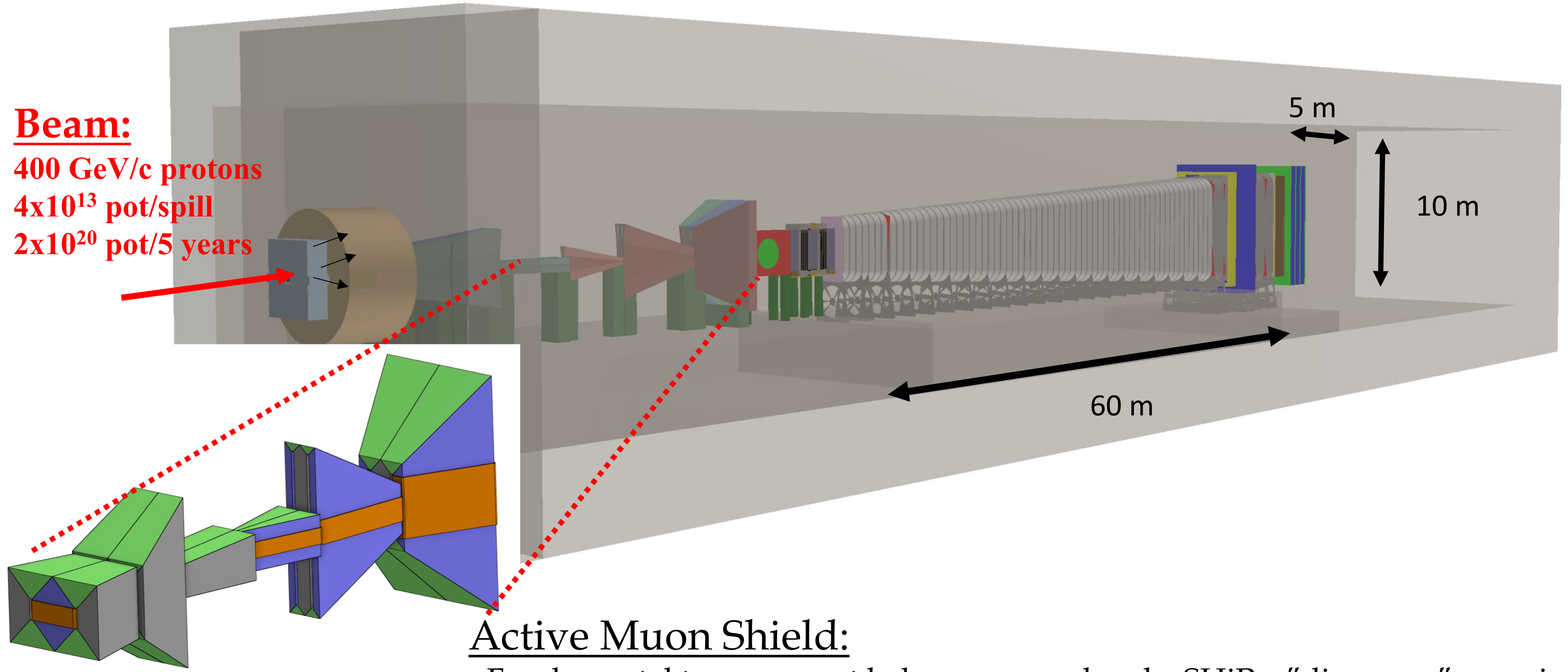
Interim spokesperson:
Andrey Golutvin, Imperial College, London

✓ Hidden particles have very feeble couplings, hence they are (very) long-lived:
  - The 60m-long, in-vacuum SHiP decay volume allows us to be sensitive to extremely low couplings

✓ Hidden particles from D and B decays have large p_T:
  - SHiP large geometrical acceptance maximizes detection of decay products

SHiP @ BDF: Active Muon Shield

Beam:
400 GeV/c protons
$4x10^{13}$ pot/spill
$2x10^{20}$ pot/5 years



Active Muon Shield:

- Fundamental to sweep out halo muons and make SHiP a "discovery" experiment.
- Big object of 6 M£, under development in UK and Russia (five UK groups involved):
  - will be built in industry (exploring possibilities in UK);
- It will require a common effort from CERN and the Collaboration

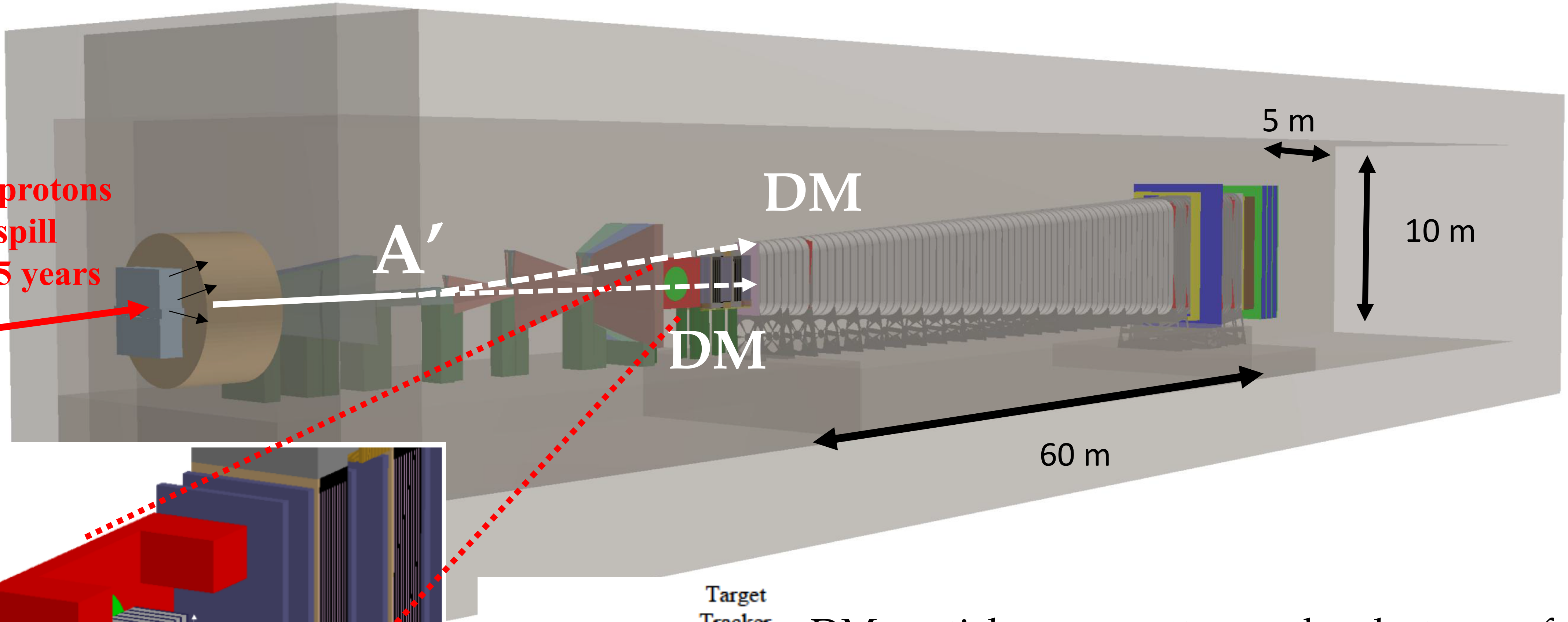
SHiP @ BDF: Light Dark Matter direct detection

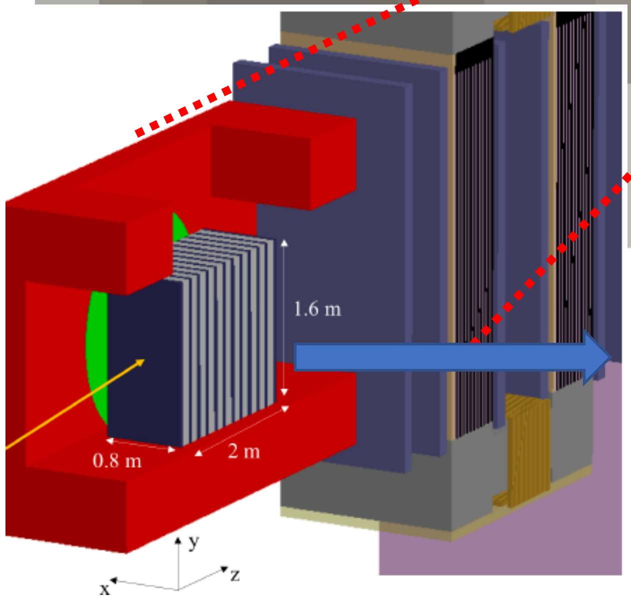
Beam:

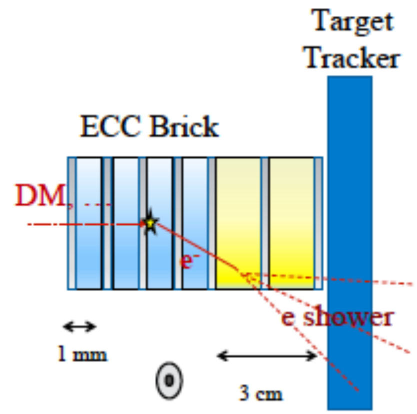
400 GeV/c protons

$4x10^{13}$ pot/spill

$2x10^{20}$ pot/5 years

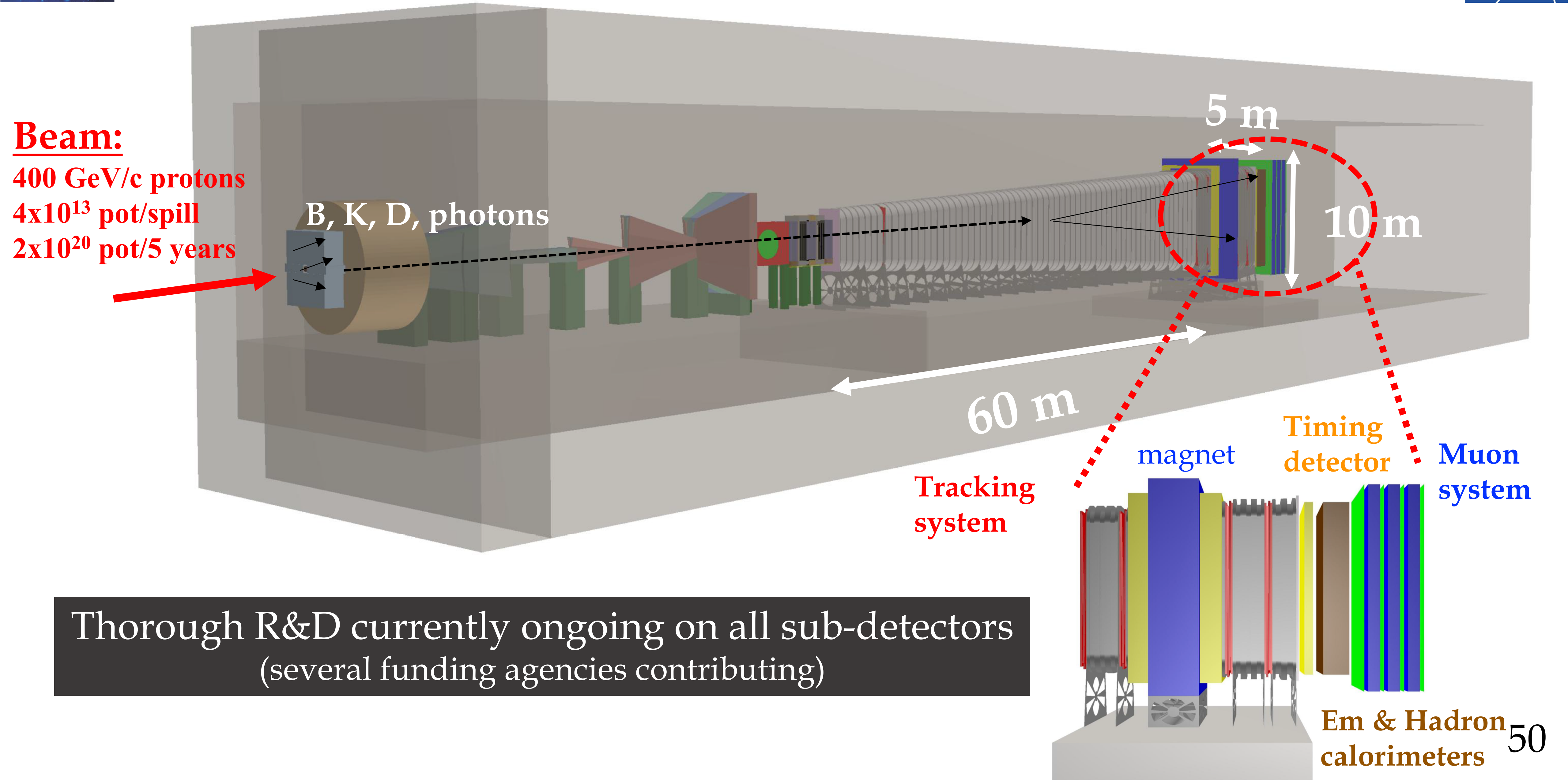






DM particles can scatter on the electrons of the dense material of the Emulsion Spectrometer in the Upstream Detector.
The same detector will do tau neutrino physics.

SHiP @ BDF: Hidden Sector Spectrometer



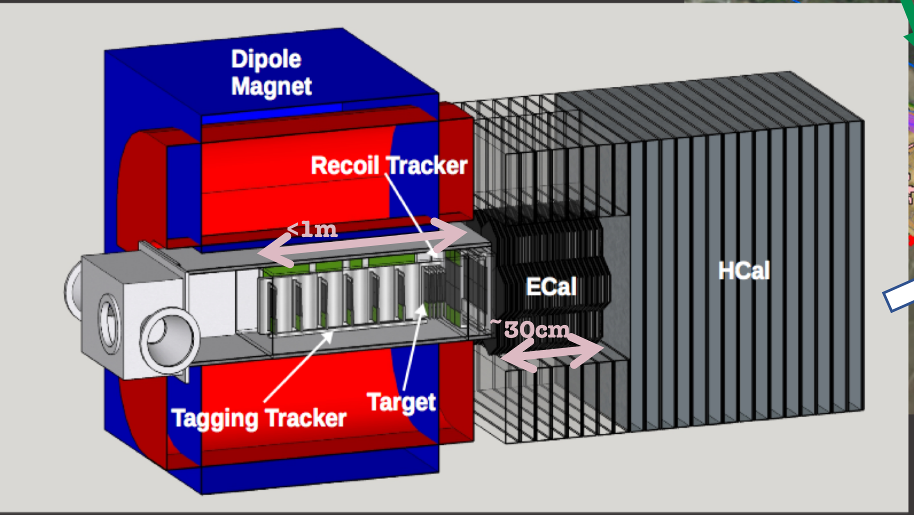
Thorough R&D currently ongoing on all sub-detectors
(several funding agencies contributing)

LDMX @ eSPS

GREEN: ~16 GeV electron beam in SPS
slow extraction towards Meyrin side for LDMX-like experiment

Electron beam impinging on target:

- multi-GeV electrons
- 1-200 MHz bunch spacing
- Ultra-low O(1-5) electrons per bunch



70 m long, 3.5 GeV X-band LINAC with excellent beam quality

- **CLEAR type of research programme.**
- **Fill SPS in 1-2 sec (bunches 5 ns apart) via TT60;**

Steinar Stapnes, Torsten Akesson, Lyn Evans et al.
~100 pp Report in preparation for the ESPP

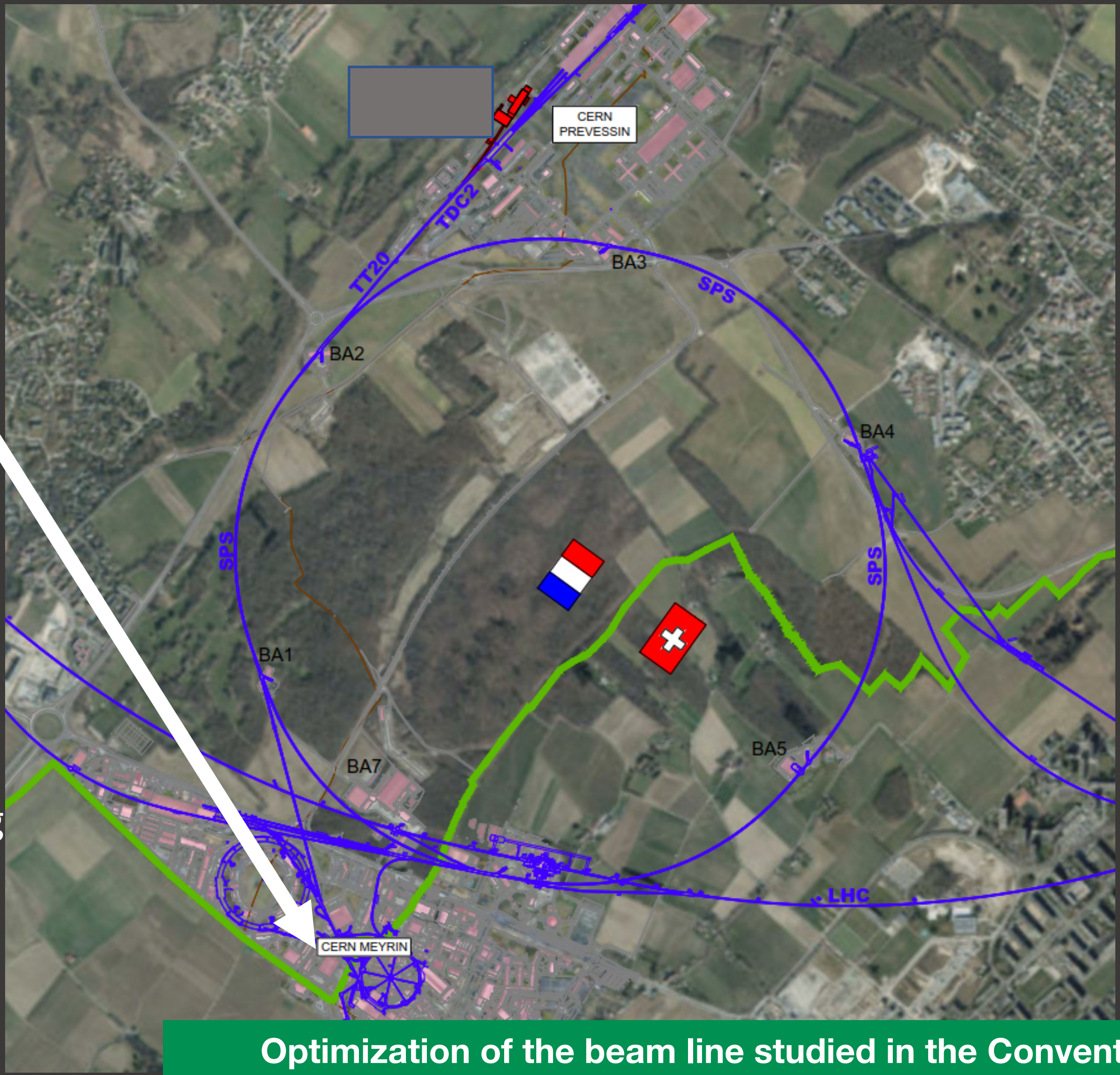
RedTop @ CERN PS

1.8 or 3.5 GeV proton beam under study at the CERN PS, use narrow eta/eta' resonances to look for Dark Scalar/Dark Photons in the reactions:

$$pLi \to \eta, \eta' \to A'\gamma \to \ell^+\ell^-\gamma \ (\ell = e, \mu)$$

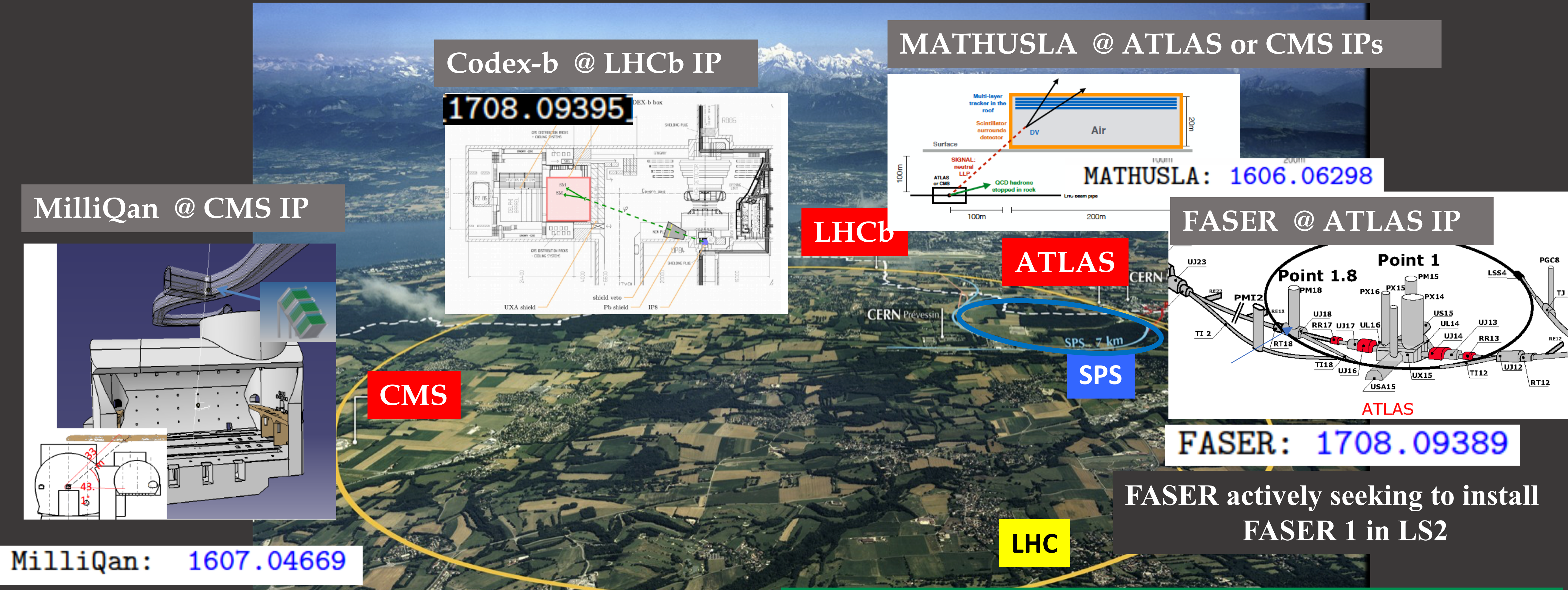
$$pLi \to \eta \to S\pi^0 \to \ell^+\ell^-\gamma\gamma$$

Request of ~ 10^{18} pot put strong constraint on duty cycle and could potentially affect other PS users. Studies with 10^{17} pot have been performed.



Optimization of the beam line studied in the Conventional Beams WG (L. Gatignon et al., ~100 pp Yellow Report in preparation for the ESPP)

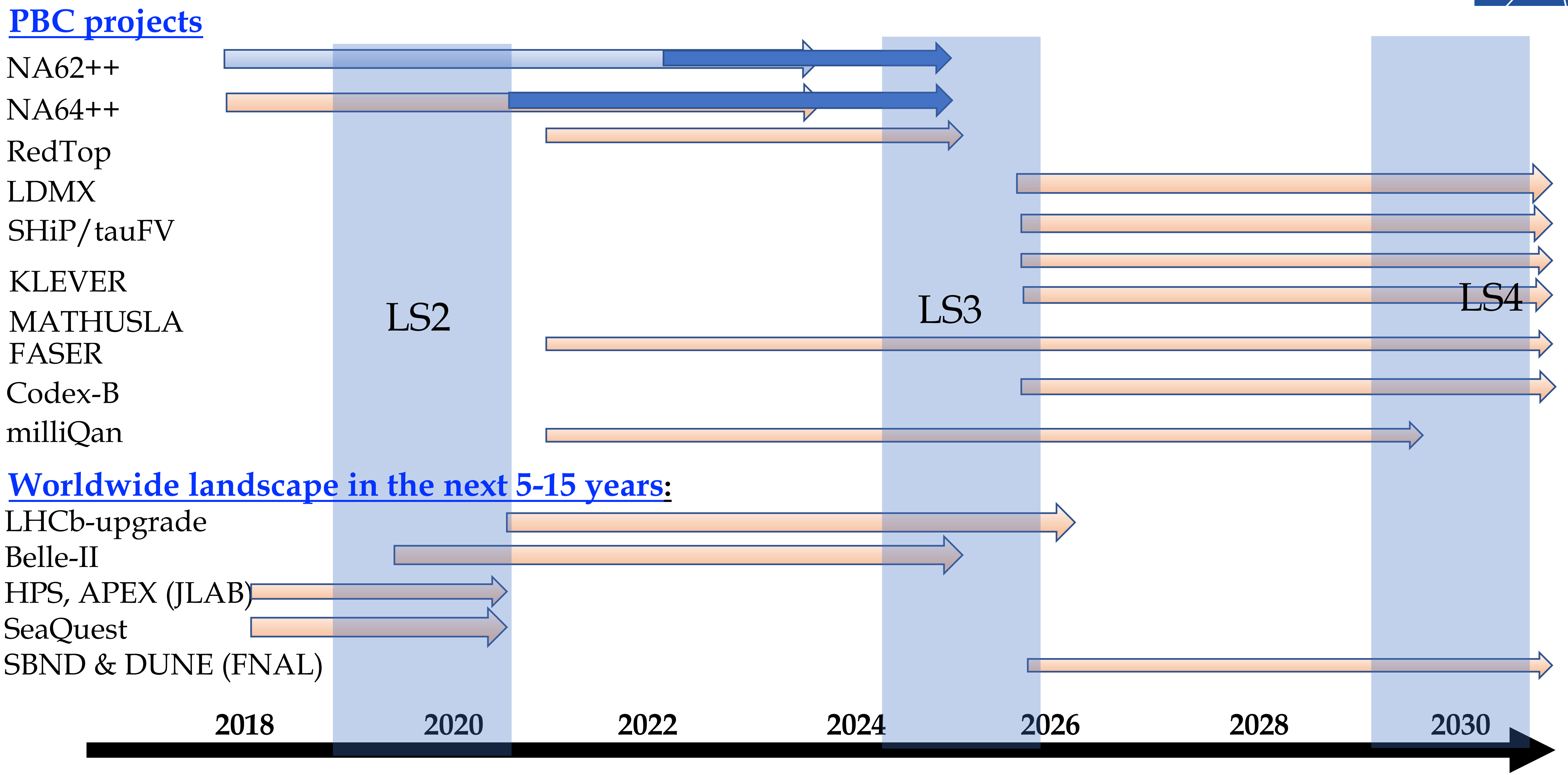
MilliQan, MATHUSLA, FASER, Codex-b @ the LHC IPs



See talks from D. Curtin, J. Lee Feng, M. Papucci, A. Haas and J. Beacham at the PBC workshop, June 2018

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

Timescale of the PBC BSM projects accelerator-based



Worldwide competition:
Eg: current and proposed experiments searching for Dark Photons

Searches for A’ → visible states

Name	Where	Source	Intensity	Production mode	Detection mode	Status
Belle-II	Super KEK-B	$e^+e^- \to \Upsilon(3S)$	> 100 fb^{-1} @ $\Upsilon(3S)$	$\Upsilon(3S) \to \gamma A'$	$A' \to e^+e^-, \mu^+\mu^-$	Commis. 2018
Apex	JLAB	e^-, 2 GeV	10^9 EOT (W)	A'-strahlung	$A' \to e^+e^-$	Commis. 2018
HPS	CEBAF12 @ JLAB	e^-,1-2 GeV	10^{14} EOT (W)	A'-strahlung	$A' \to e^+e^-$	Running 2016-20
MAGIX	MESA @ Mainz	e^-, 155 MeV	10^{16} EOT (Xe gas)	A'-strahlung	$A' \to e^+e^-$	Commis. 2020
Mu3e	πE5 line @ PSI	μ^-, 28 MeV	10^{15-16} μ^-	$\mu \to \nu\nu A'$	$A' \to e^+e^-$	Commis. 2017
ATLAS/CMS	LHC @CERN	pp 8, 13 TeV	few fb^{-1}	$H \to 4l$ + MET	$A' \to \mu^+\mu^-$	Running
LHCb	LHC @CERN	pp,13 TeV	15 fb^{-1}	$D^* \to DA'$	$A' \to e^+e^-, \mu^+\mu^-$	Running
NA62	SPS @CERN	p, 400 GeV	2 10^{18} POT	Meson, A'-strahlung	$A' \to e^+e^-, \mu^+\mu^-$	Running -2018
SeaQuest	Main Inj. @ FNAL	p, 120 TeV	1.5	Meson, A'-strahlung	$A' \to \mu^+\mu^-$	Proposed 2017-19
SHiP	SPS @CERN	p, 400 GeV	2 10^{20} POT	Meson, A'-strahlung	$A' \to e^+e^-, \mu^+\mu^-$	Proposed 2026

Searches for A’ → invisible states

Babar	PEP-II @ SLAC	$e^+e^- \to \Upsilon(3S)$	57 fb^{-1}	$\Upsilon(3S) \to \gamma A'$	Single-γ trigger	ICHEP 2016
VEPP-3	VEPP-3 @ Budker Inst.	e^+, 500 MeV	1.5 MHz $\gamma\gamma$	$e^+e^- \to A'\gamma$	detect $\gamma + M_{miss}$	Proposed
PADME	BTF @ Frascati INFN	e^+, 550 MeV	15 Hz $\gamma\gamma$	$e^+e^- \to A'\gamma$	detect $\gamma + M_{miss}$	Approved, 2017-19
MMAPS	CESR @ Cornell	e^+, 5.3 GeV	2.2 MHz $\gamma\gamma$	$e^+e^- \to A'\gamma$	detect $\gamma + M_{miss}$	Not funded
NA64	SPS @ CERN	e^-, 100 GeV	$e^-N \to e^-NA'$	10^9–10^{12} EOT	detect $e^- + E_{miss}$	Running, 2016-17
LDMX	LCLS-II @ SLAC	e^-, 4 GeV	$e^-N \to e^-NA'$	10^{15}–10^{16} EOT	detect $e^- + E_{miss}$	Proposed, 2020

Direct detection of LDM via the process A’ → LDM with LDM scattering in the detector

SBND	FNAL	p, 9 GeV	2 10^{20} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 110 m	Under study
T2K	Tokai-Kamioka	p, 30 GeV	10^{21} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 280 m	Running
COHERENT	SNS @ Oak Ridge	p, 1 GeV	10^{23} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 20 m 2°-OA	Proposed
SHiP	SPS @CERN	p, 400 GeV	2 10^{20} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 100 m	Proposed 2026
LBNF	DUNE @FNAL	p, 120 GeV	3 10^{21} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 500 m	Under study 2020

A lively and continuously increasing community all around the world

(in particular in US: see for example, Cosmic Visions, arXiv:1707.04591)

Physics Reach of projects of PBC-BSM WG: MeV-GeV mass range

Physics Reach of projects of PBC-BSM WG: MeV-GeV mass range

The experiments have provided sensitivity curves as 90% CL exclusion limits with respect to the 11 reference Benchmark Cases.

This provided us with a common language and a common ground for discussions, and allowed us to put each proposal into the worldwide landscape.

The evaluation of backgrounds and other experimental effects is a long-term project and is to date very non-homogeneous among the proposals.

The PBC BSM document in preparation for the ESPP will reflect the state-of-the-art of these studies

Disclaimer:

the plots that follow must be considered "work in progress"
Final plots will be included in the PBC-BSM deliverable for the ESPP

PBC BSM Physics Programme: benchmark models

The BSM WG has selected a set of theoretically and phenomenologically motivated target areas used as benchmarks models to explore the physics reach of the received proposals and put them into the worldwide landscape. This allowed us to have a common ground and a common language.

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	$y_N LHN$

- **Vector portal models:**
  - Dark Photon with coupling to SM particles (**BC1**)
  - Dark Photon with coupling to DM particles (**BC2**)
  - Milli charged particles (**BC3**)
- **Scalar portal models:**
  - Higgs mixed scalar (**BC4**) , Higgs- mixed scalar with large pair production particles (**BC5**)
- **Axion and axion-like portals:**
  - photon (**BC9**), fermion (**BC10**), gluon coupling **(BC11)**
- **Neutrino portals:** with e, mu or tau coupling (**BC6, 7, 8**)

PBC projects: current status of evaluation of backgrounds and other experimental effects

Proposal	Background	Efficiency	Based on
at the PS:			
RedTop	included	included	Main backgrounds and efficiencies evaluated with full Monte Carlo
at the SPS:			
KLEVER	$K_L \to \pi^0 \nu\overline{\nu}$, $K_L \to \pi^0\pi^0$ bkgs included	included	full simulation
LDMX	background included	included	full Geant4 simulation
NA62^{++}	zero background proven for fully reconstructed final states	partially included	analysis of $\sim 10^{16}$ pot in dump mode
NA64$^{++}(e)$	included	included	background, efficiencies evaluated from data
NA64$^{++}(\mu)$	in progress	in progress	test of the purity of the M2 line with COMPASS setup
NA64$^{++}(K_{S,L}, \eta, \eta')$	to be done	to be done	–
SHiP	zero background	included	Full Geant4 simulation, digitization and reconstruction $\nu-$ interactions based on 2×10^{20} pot $\mu-$ combinatorial and $\mu-$ interactions based on 10^{12} pot measurement of the muon flux at H4 planned for July 2018
at the LHC:			
Codex-b	zero background	included	Evaluation of background in progress with full MC
FASER	zero bkg assumed	not included	Fluka simulation
MATHUSLA	zero background	assumed 100%	neutrino background: atmospheric ν flux from Frejus data arXiv:hep-ph/0607324. LHC ν flux from Pythia+MadGraph+Geant4 for simplified detector geometry ν interactions with air in MATHUSLA used measured ν cross sections muon background from LHC: MADGRAPH + measured cross-sections in air cosmic rays: measured flux + geometricl arguments
MilliQan	included	included	full Geant4 simulation of the detector

All details in the BSM document in preparation

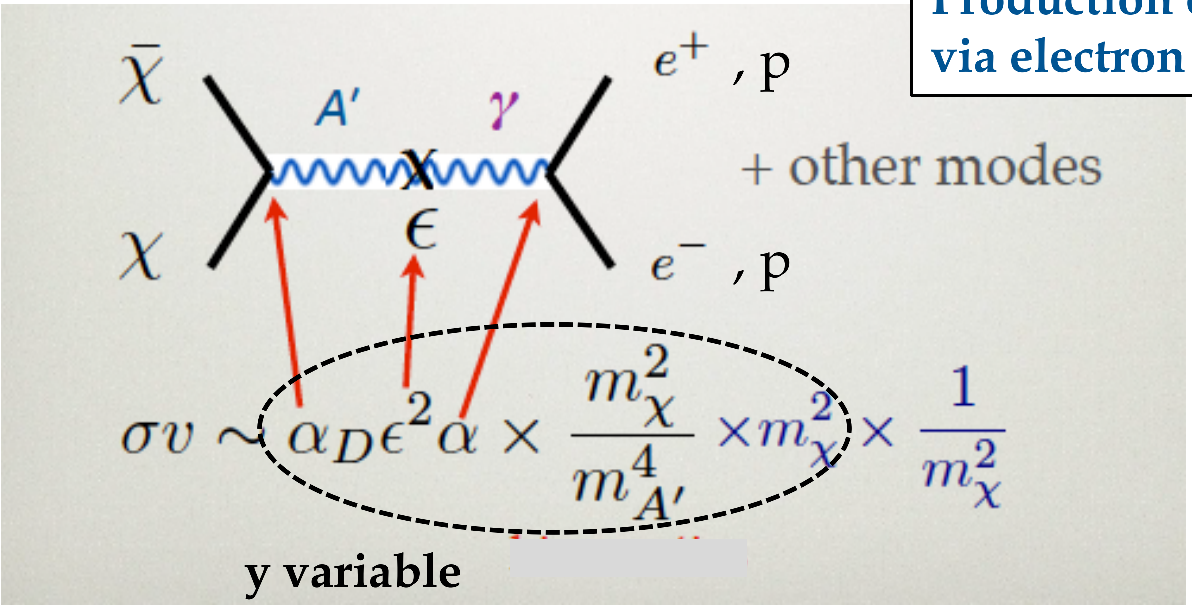
Search for light Dark Matter and related light mediators in the MeV – GeV mass range

Portal	Coupling	**Benchmark Cases.**
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	**BC1, BC2, BC3**
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$	**BC4, BC5**
Axion, a	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu} \tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a} \overline{\psi} \gamma^\mu \gamma^5 \psi$	**BC9, BC10, BC11**
Sterile Neutrino, N	$y_N L H N$	**BC6, BC7, BC8**

Light Dark Matter via Vector Portal with thermal origin: connection with direct detection and cosmological bounds

Direct DM scattering with e/protons
Direct Detection experiments

Production of DM at accelerators
via electron or proton bremsstrahlung

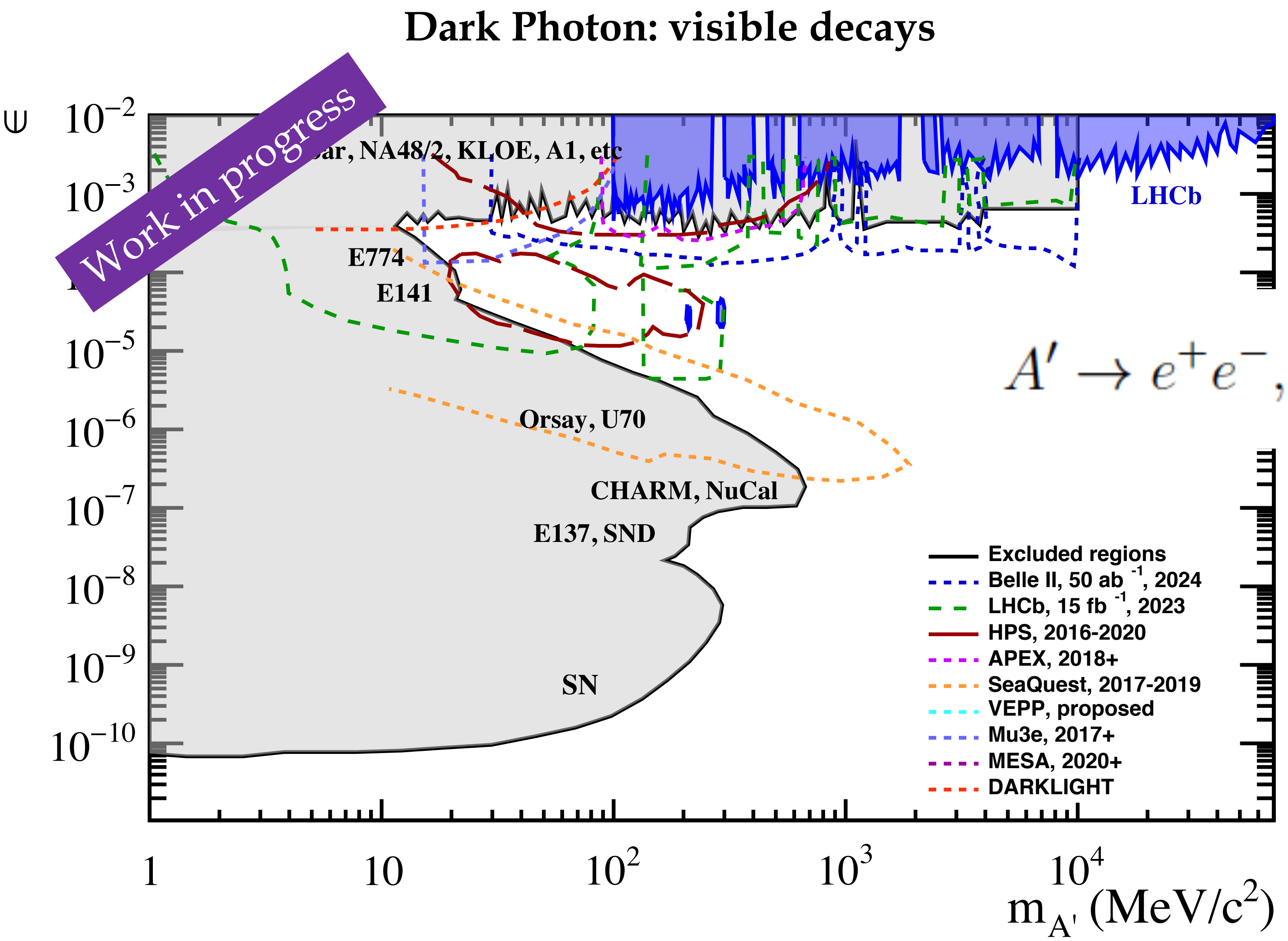


Courtesy of P. Schuster

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

If mA' < 2m $_\chi$, the Dark Photon decays to SM particles
If $m_{A'} > 2\, m_\chi$ the Dark Photon can decay to DM with a coupling $\boldsymbol{\alpha}_D$

Dark Photon decaying to SM particles: worldwide landscape



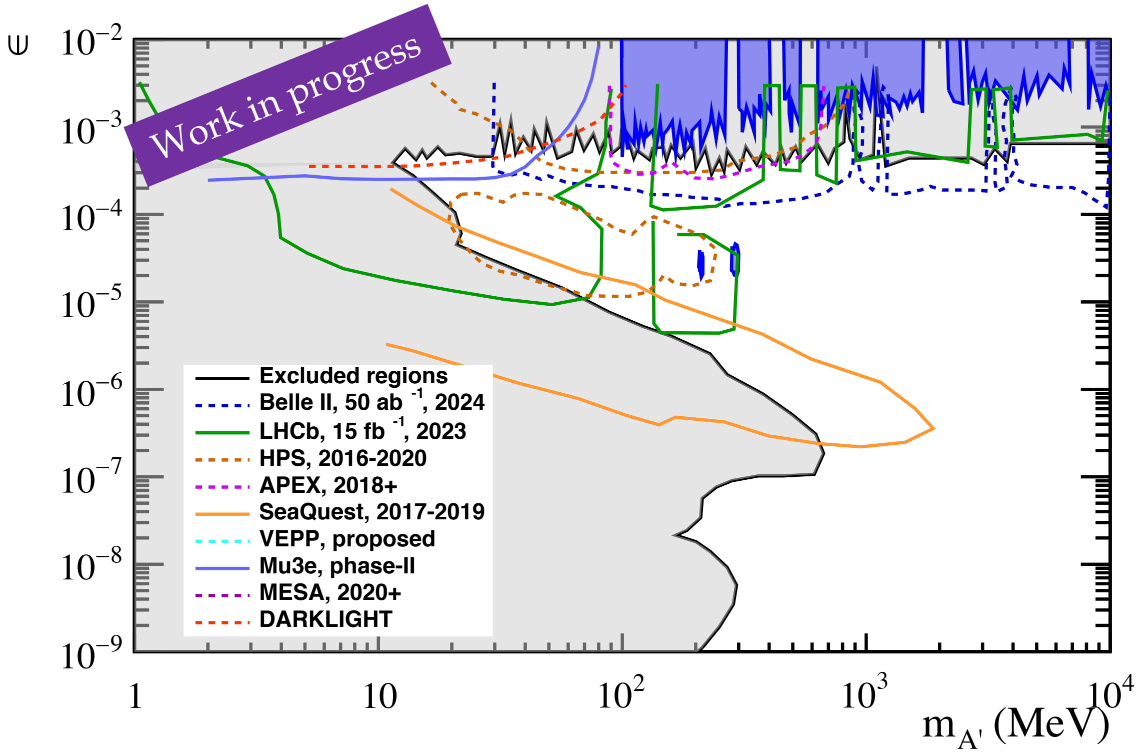
$$A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$$

BC 1

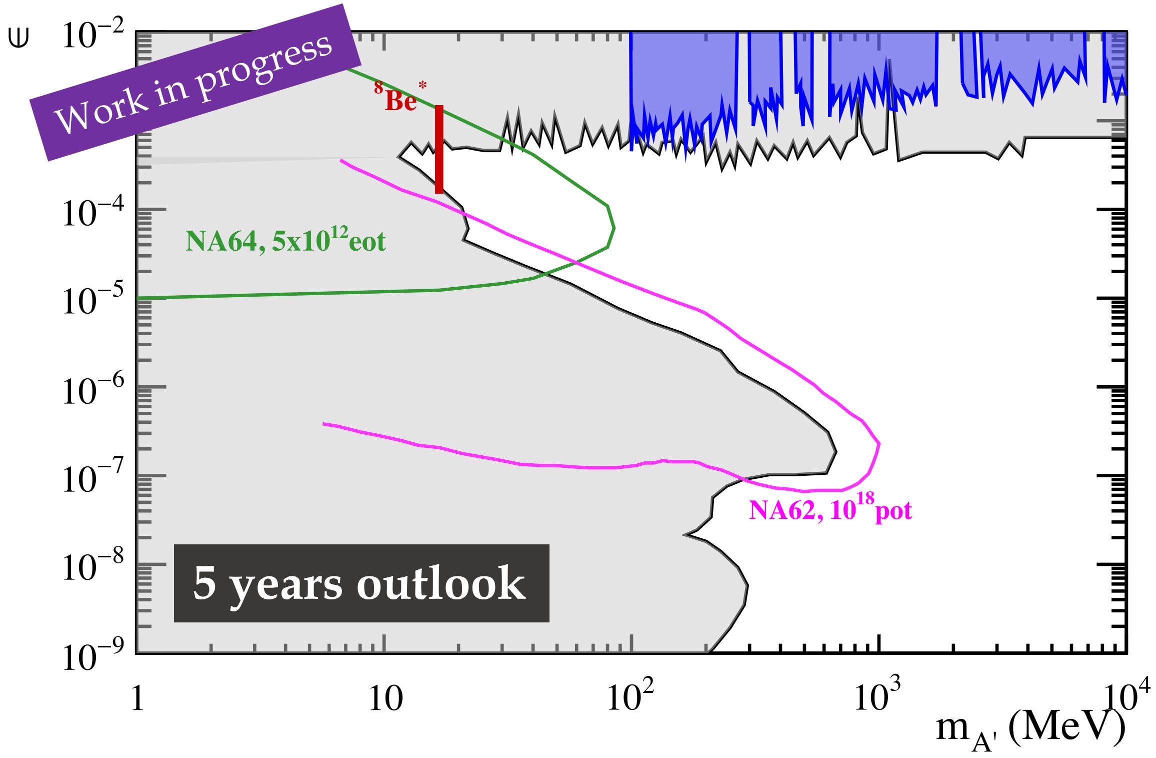
If mA′ < 2m$_{\chi}$, the Dark Photon decays to SM particles

Dark Photon decaying to SM particles

Worldwide landscape



PBC projects: 5 years outlook

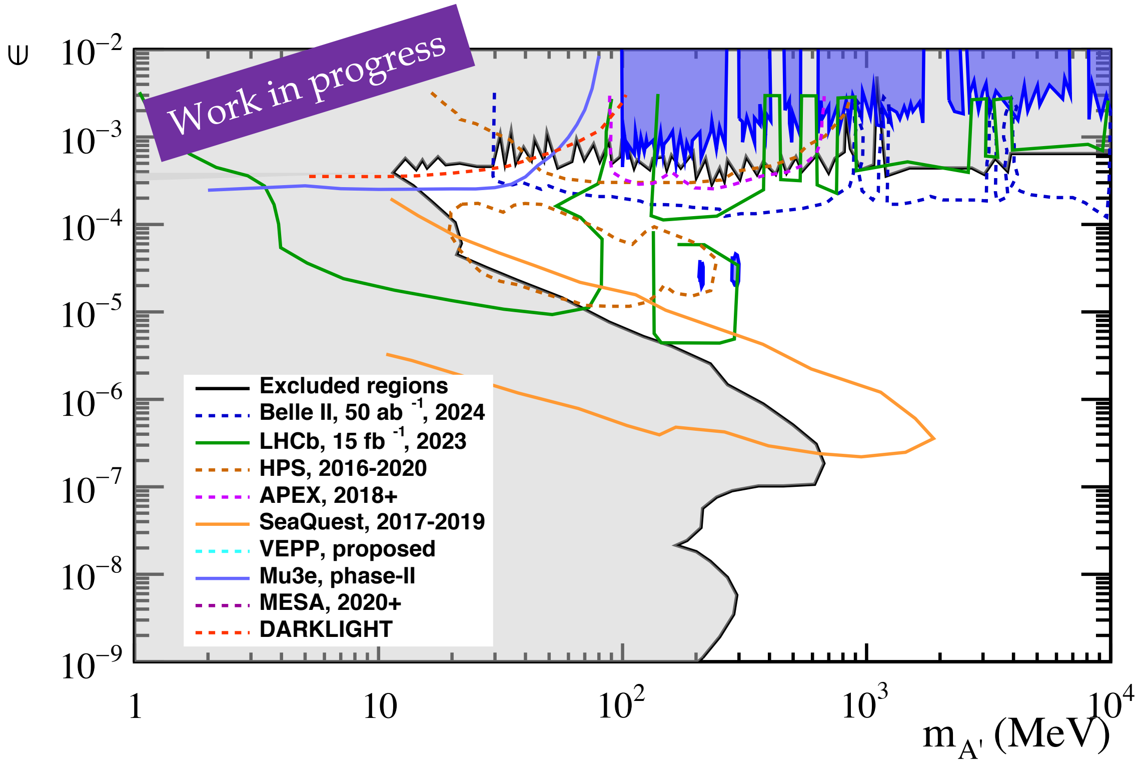


BC 1

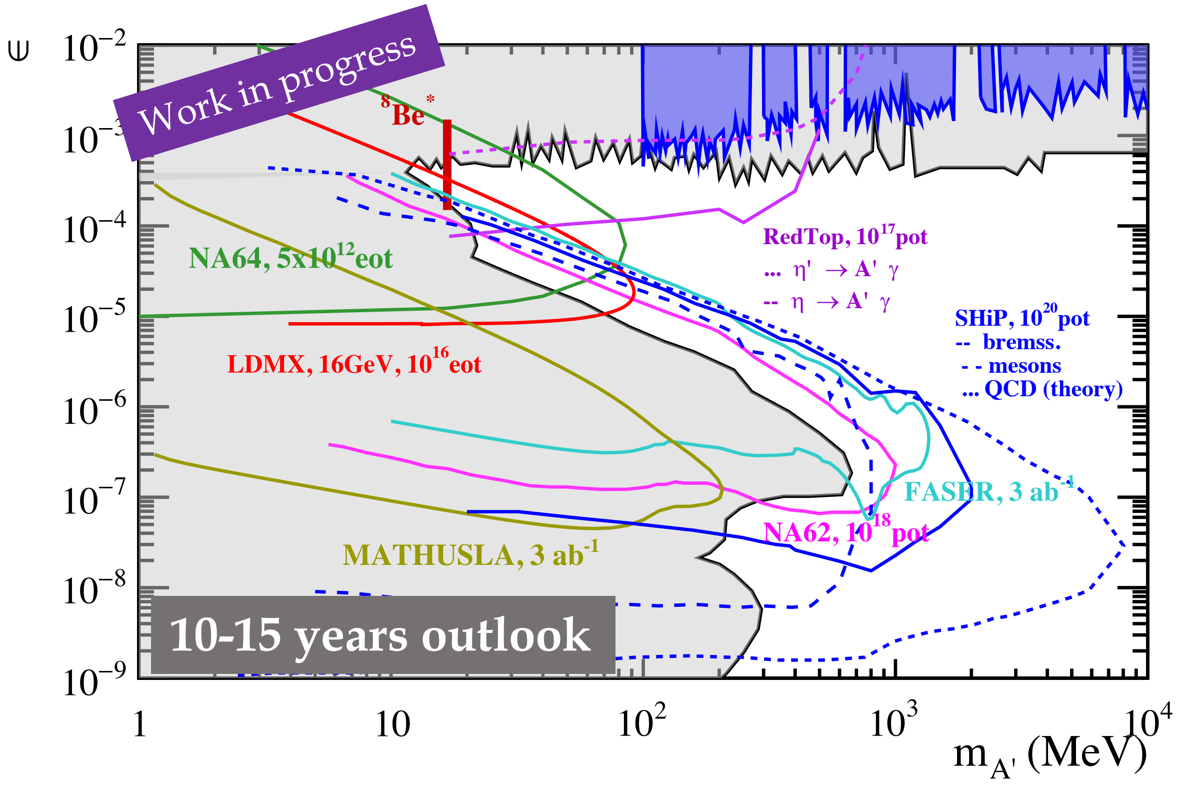
$$A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$$

Dark Photon decaying to SM particles:

Worldwide landscape



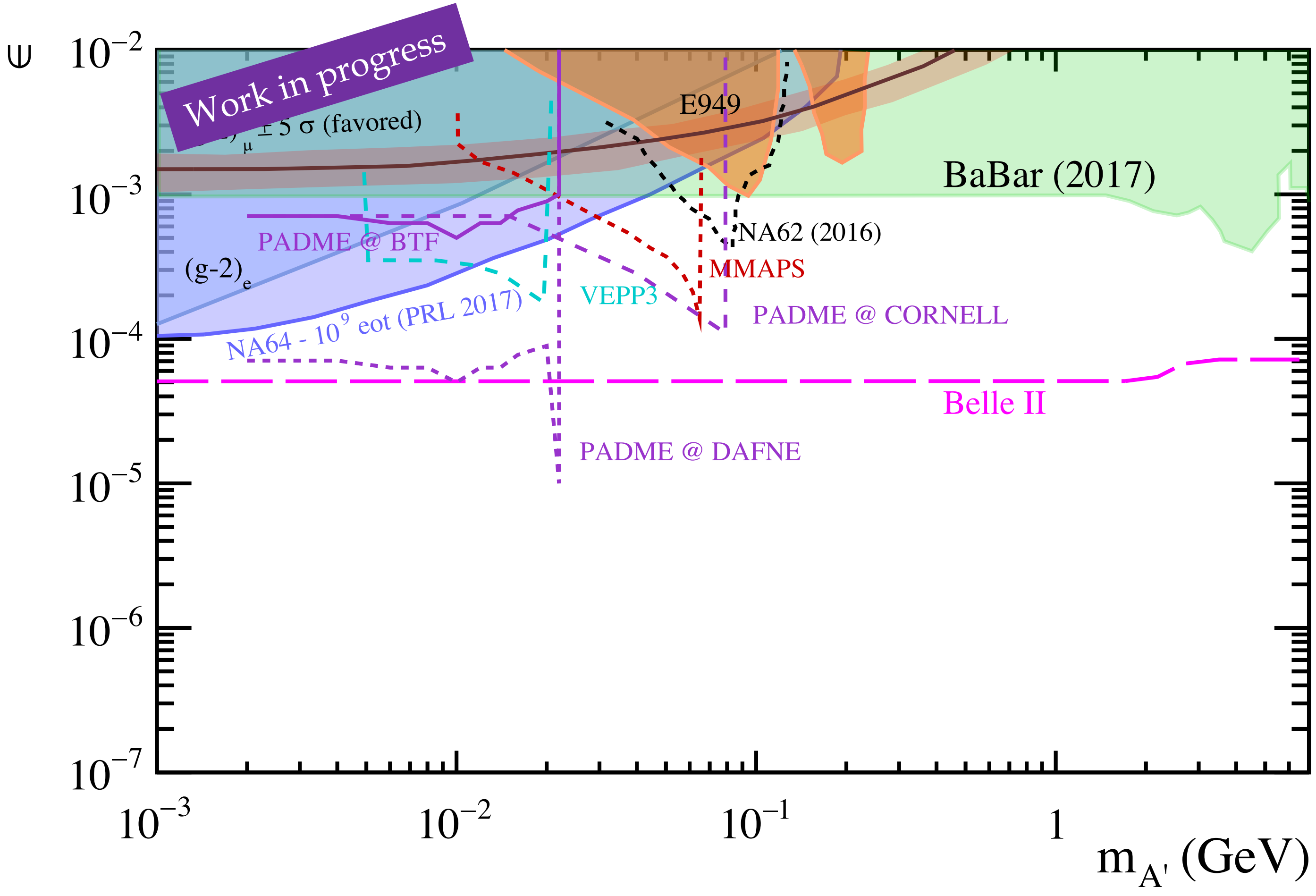
PBC projects: 10-15 years outlook



BC 1

$$A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$$

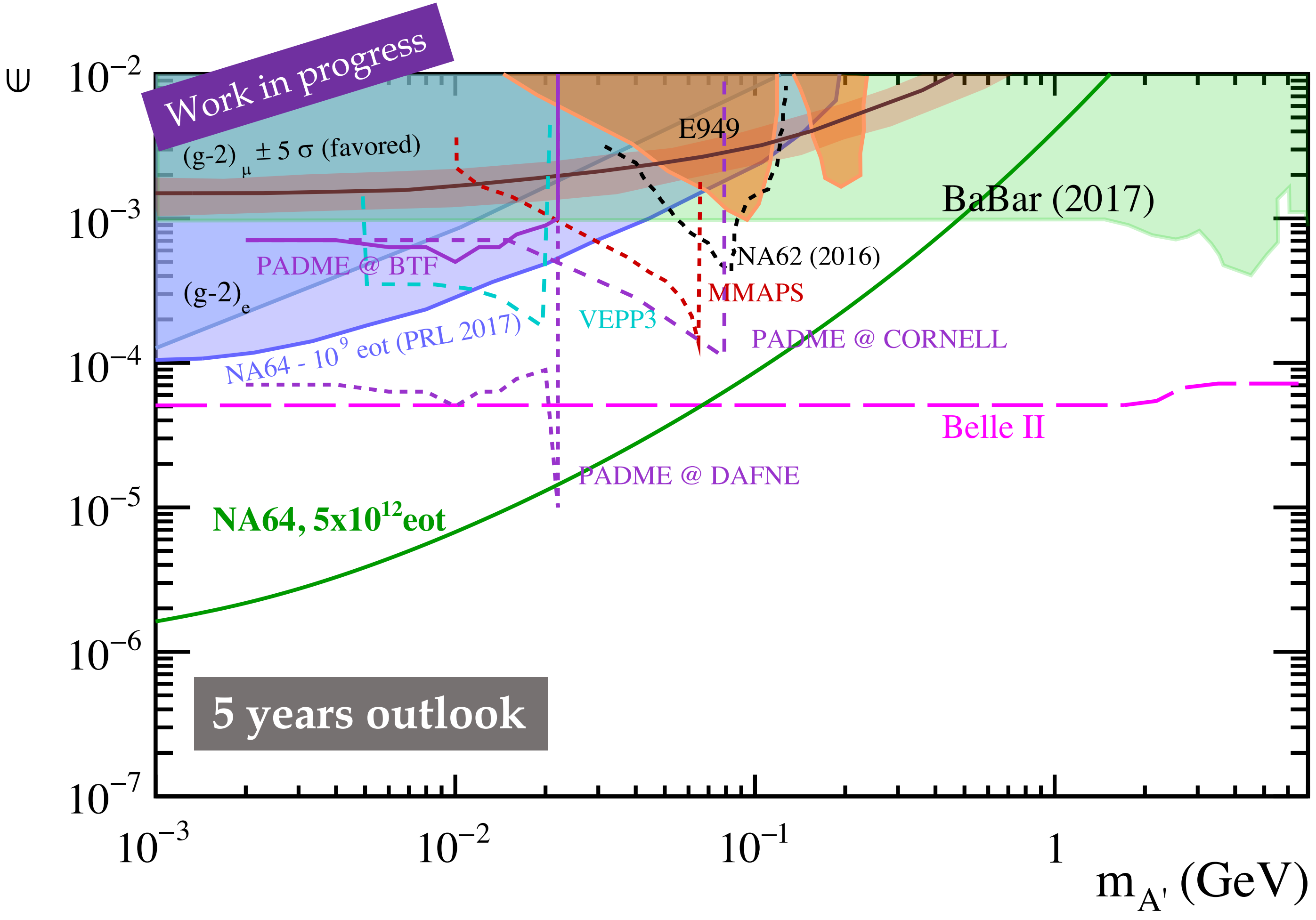
Dark Photon decaying to invisible particles: worldwide landscape



$A' \rightarrow$ invisible final states

BC 2

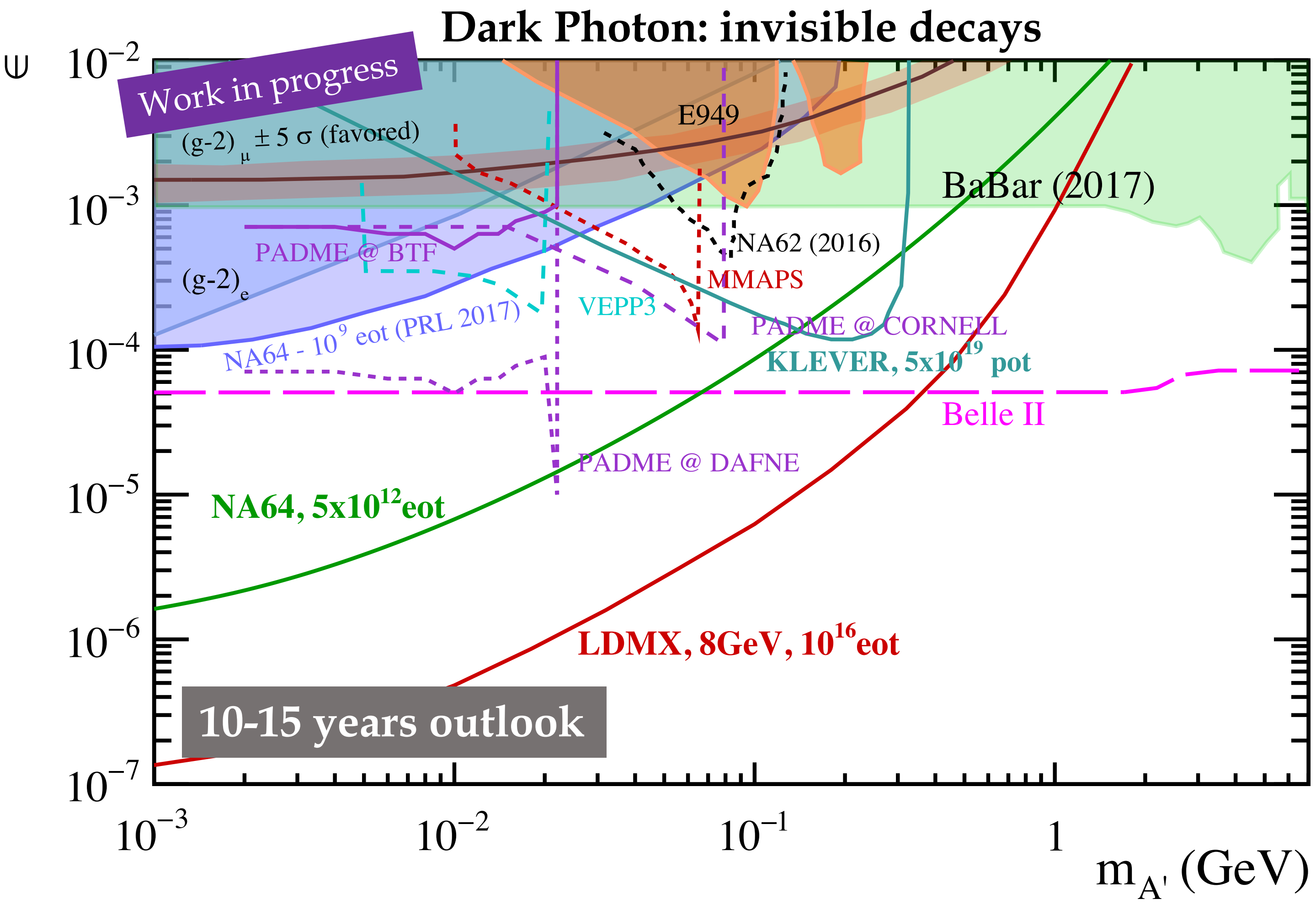
Dark Photon decaying to invisible particles: PBC projects in 5 years



$A' \to$ invisible final states

BC 2

Dark Photon decaying to invisible particles: PBC projects in 10-15 years

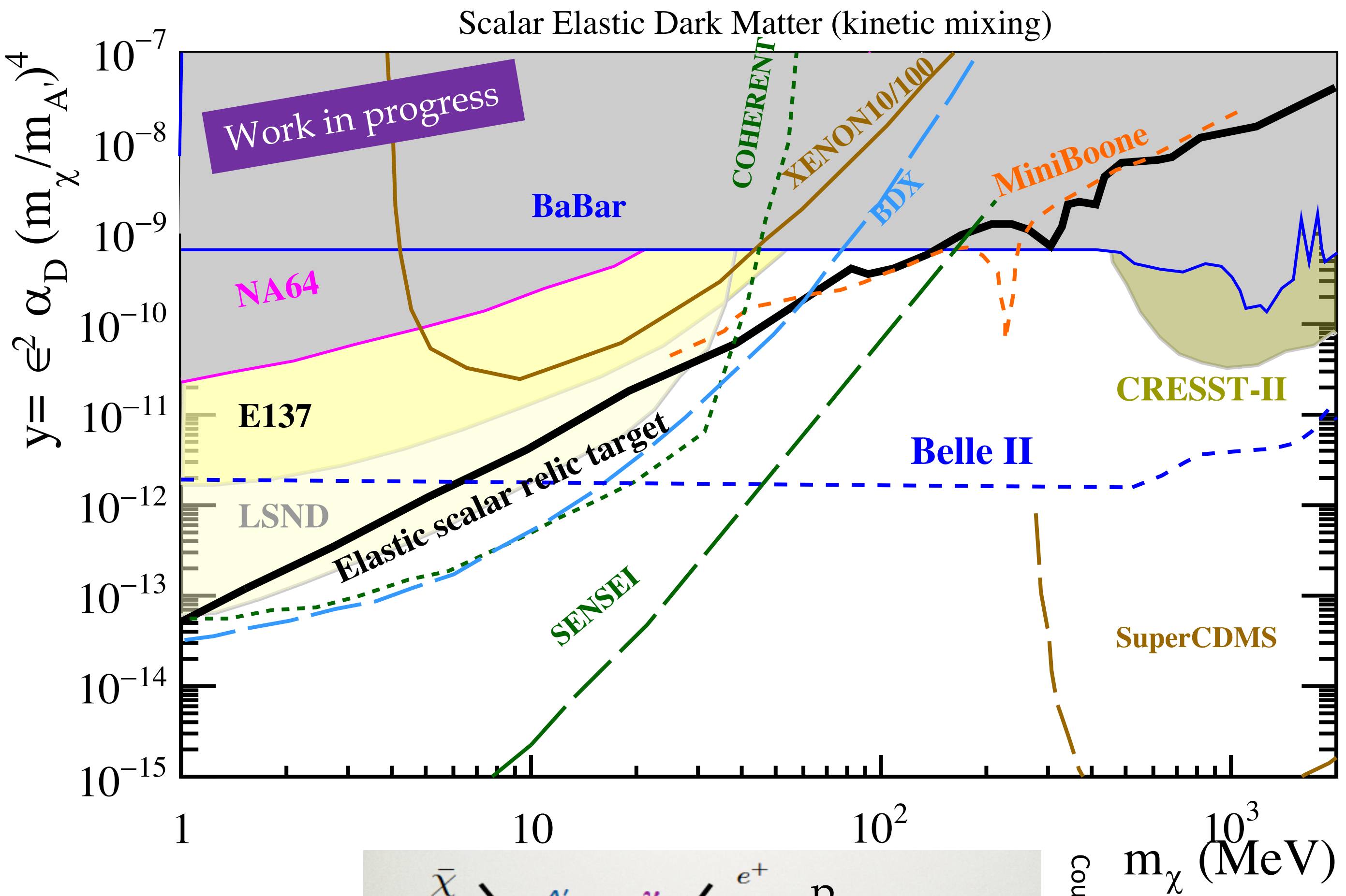


$A' \rightarrow$ invisible final states

BC 2

Dark Photon decaying to Scalar Elastic Dark Matter: worldwide landscape

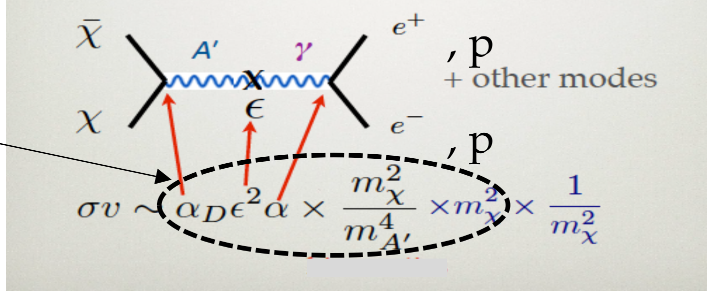
Revisited from Cosmic Visions, arXiv:1707.04591



$m(A') = 3\, m(\chi)$
$\alpha(D) = 0.1$

$A' \to \chi\chi$

y variable

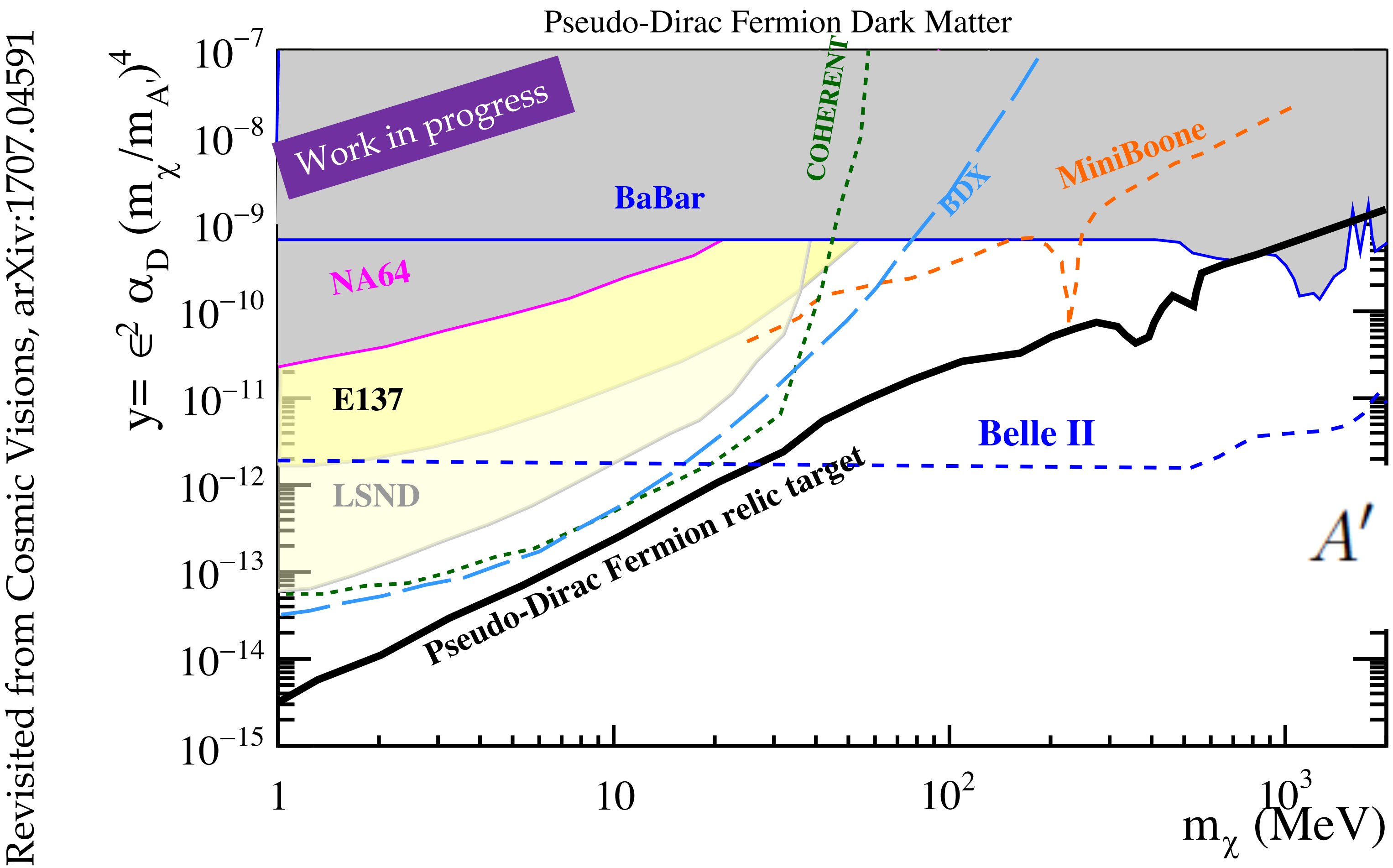


Courtesy of P. Schuster

If $m_{A'} > 2\, m_\chi$ the Dark Photon can decay to DM with a coupling $\boldsymbol{\alpha}_D$

BC 2

Dark Photon decaying to Pseudo-Dirac Dark Matter: worldwide landscape



$m(A') = 3\,m(\chi)$
$\alpha(D) = 0.1$

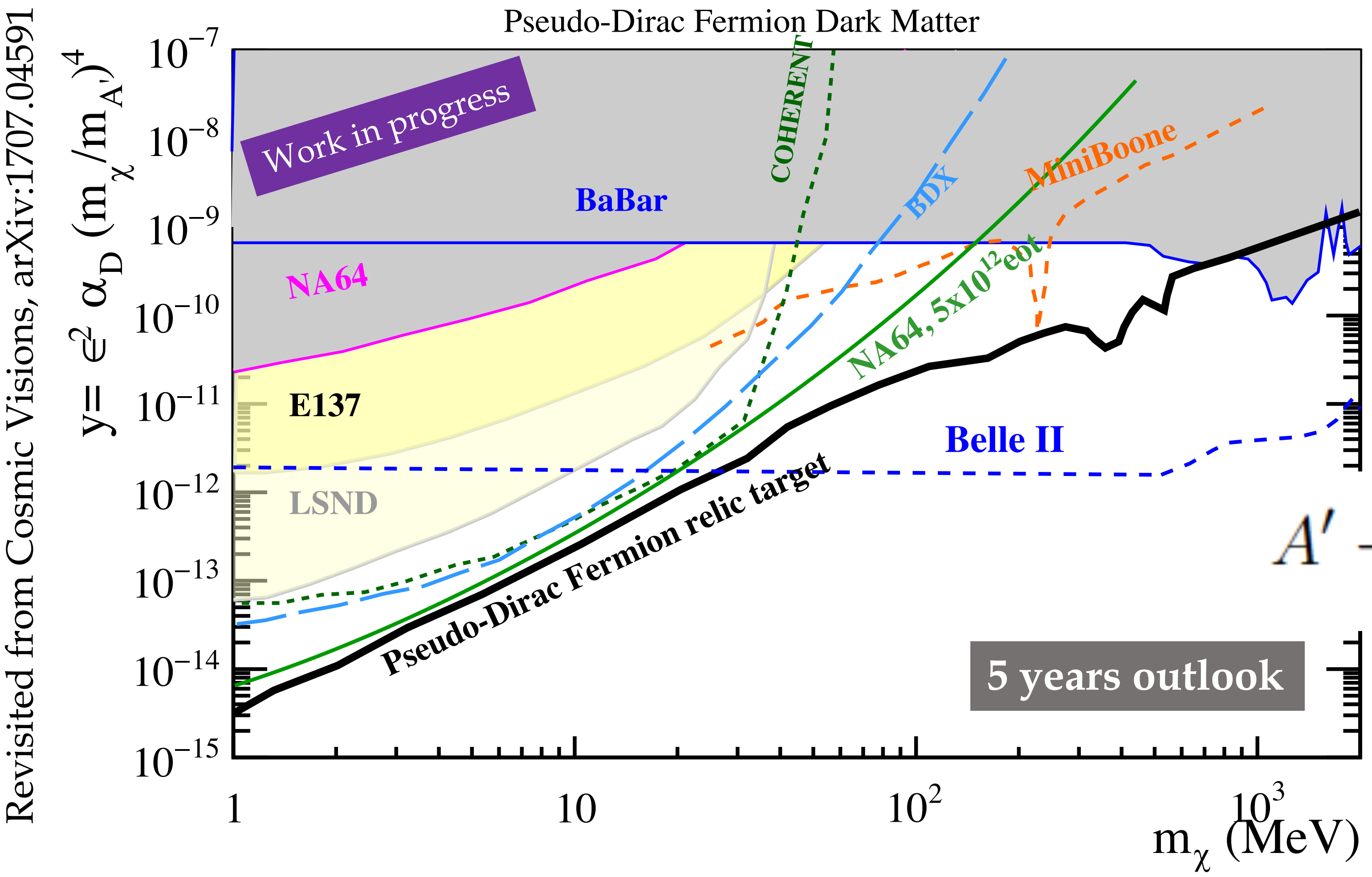
$A' \to \chi\chi$

BC 2

PBC projects considered in the following do not depend on the assumption on the nature of DM

Dark Photon decaying to Dark Matter: PBC projects in 5 years

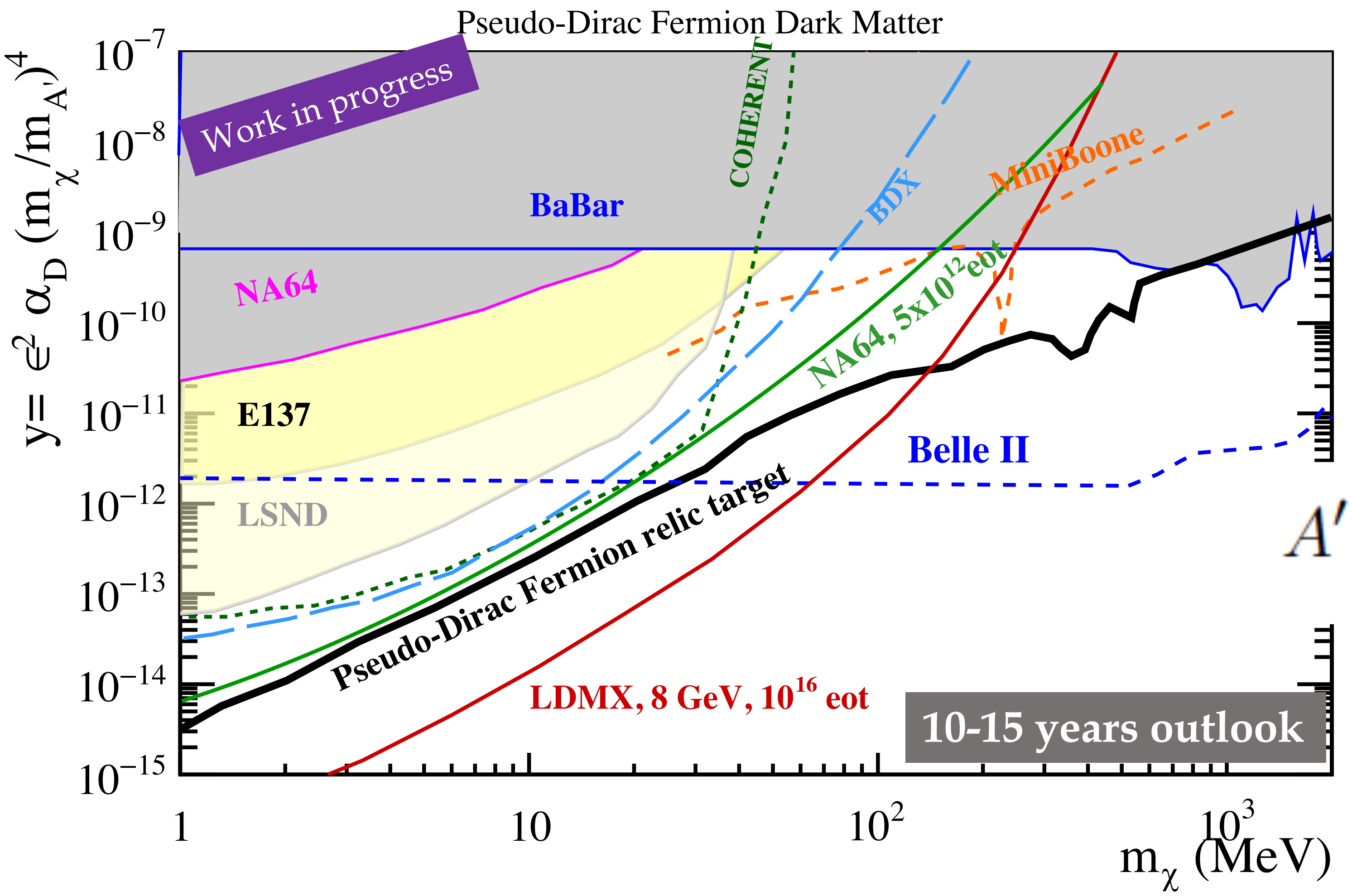
$m(A') = 3\,m(\chi)$
$\alpha(D) = 0.1$



$A' \to \chi\chi$

BC 2

Dark Photon decaying to Dark Matter: PBC projects in 10-15 years



$m(A') = 3\,m(\chi)$
$\alpha(D) = 0.1$

$A' \to \chi\chi$

BC 2

Physics Beyond Colliders

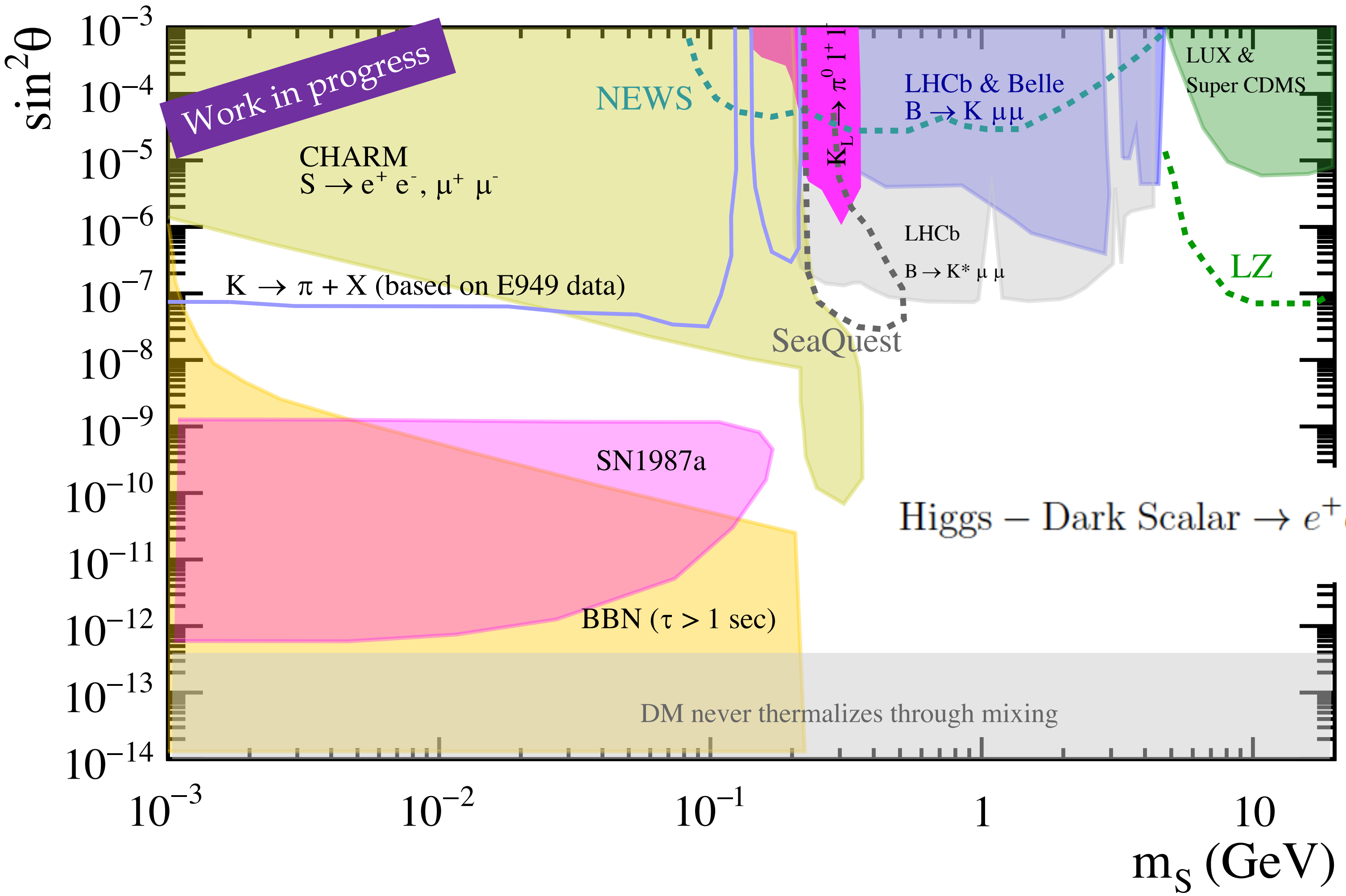
CERN

Search for light Dark Matter and related light mediators in the MeV – GeV mass range

Portal	Coupling	Benchmark Cases.
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	BC1, BC2, BC3
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$	BC4, BC5
Axion, a	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$	BC9, BC10, BC11
Sterile Neutrino, N	$y_N LHN$	BC6, BC7, BC8

The discovery of the Higgs , prompts to investigate the so called scalar or Higgs portal,
that couples the dark sector to the Higgs boson via the bilinear H^+H operator of the SM.
The minimal scalar portal model operates with one extra singlet field S and two types of couplings, μ and λ.

Light Dark Scalar mixing with the Higgs: worldwide landscape

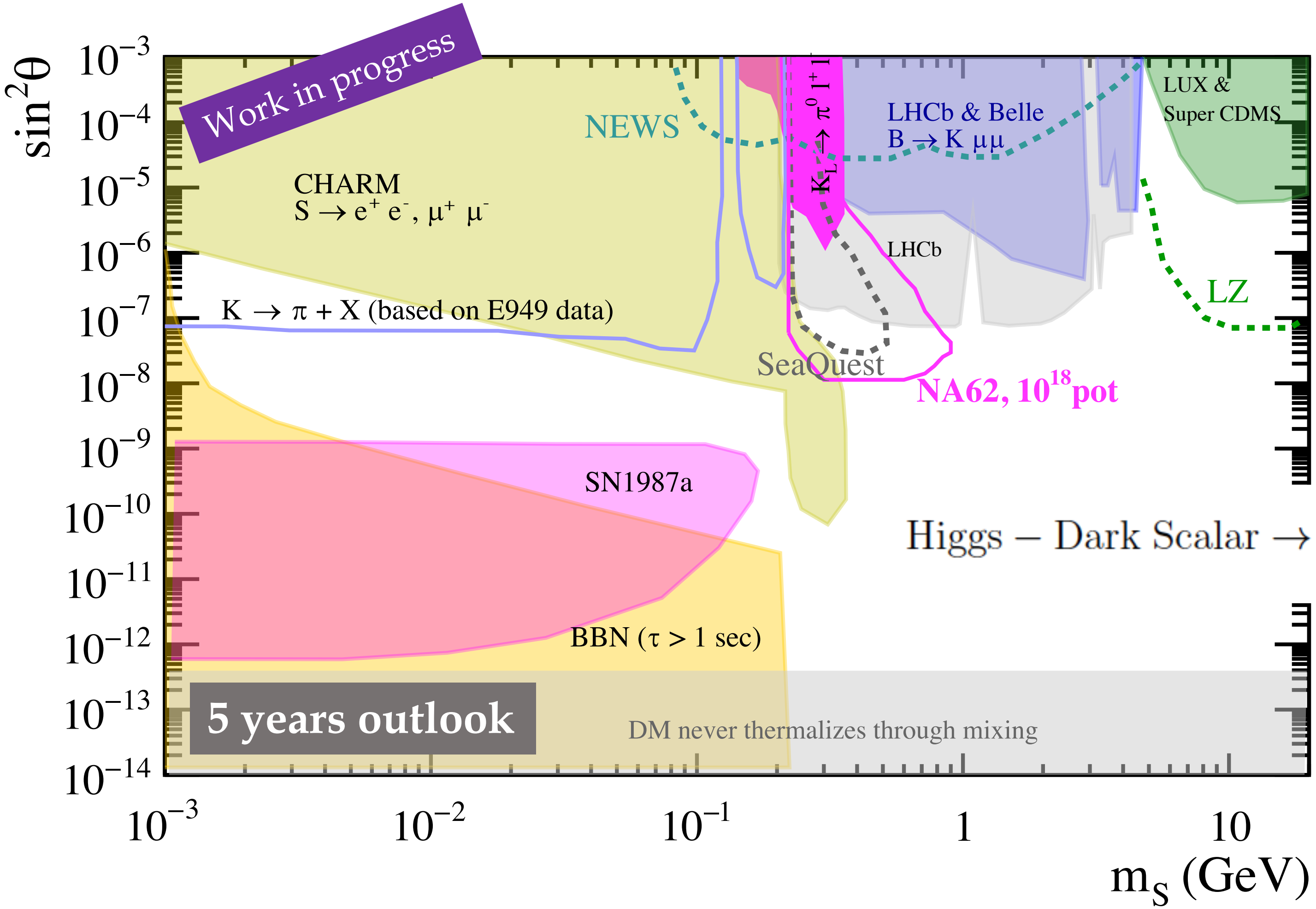


Higgs – Dark Scalar $\to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$

Dark Higgs, S $\quad (\mu S + \cancel{\lambda S^2}) H^\dagger H$

BC 4

Light Dark Scalar mixing with the Higgs: PBC projects in 5 years

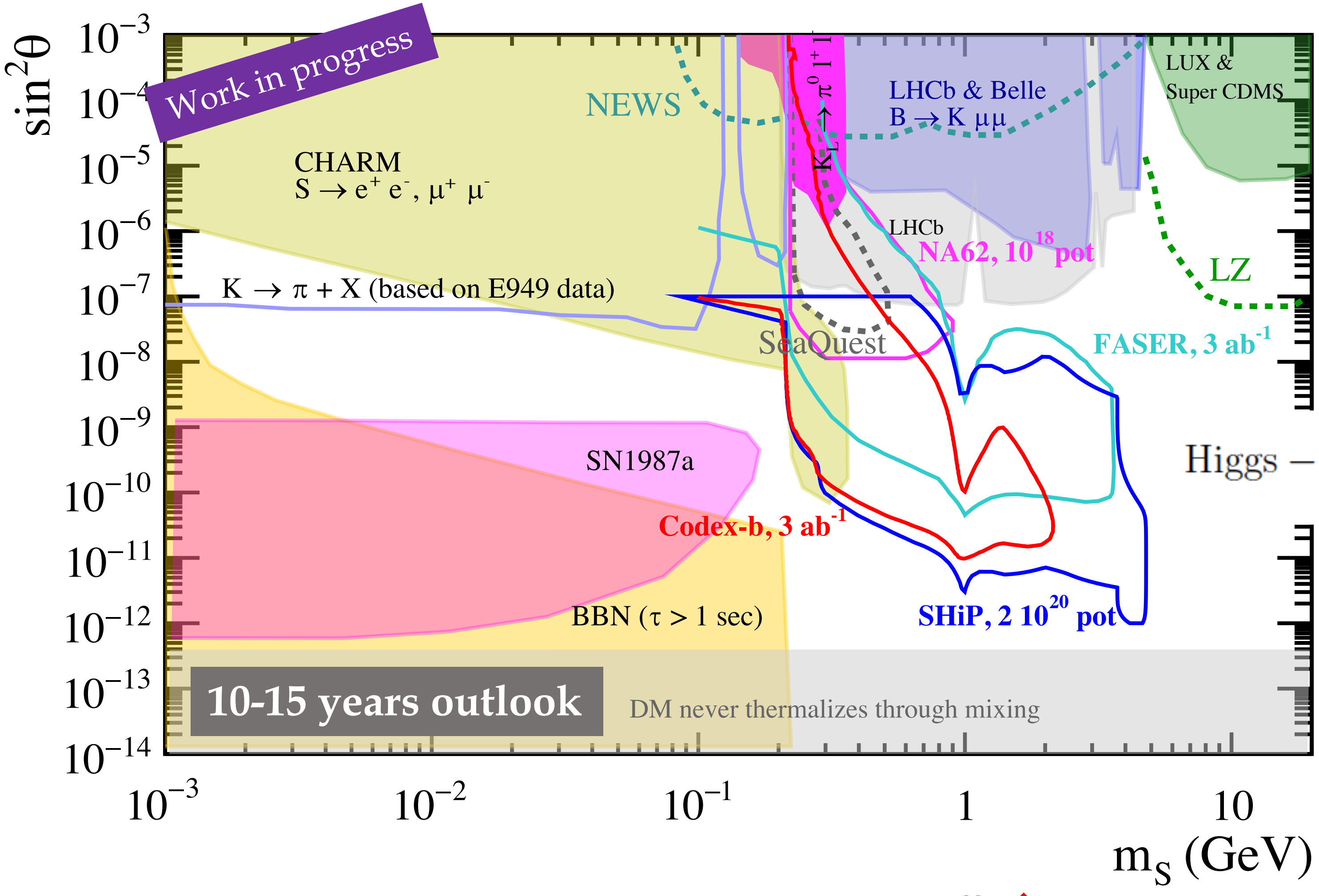


Higgs – Dark Scalar $\to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$

Dark Higgs, S $\quad (\mu S + \cancel{\lambda S^2}) H^\dagger H$

BC 4

Light Dark Scalar mixing with the Higgs: PBC projects in 10-15 years

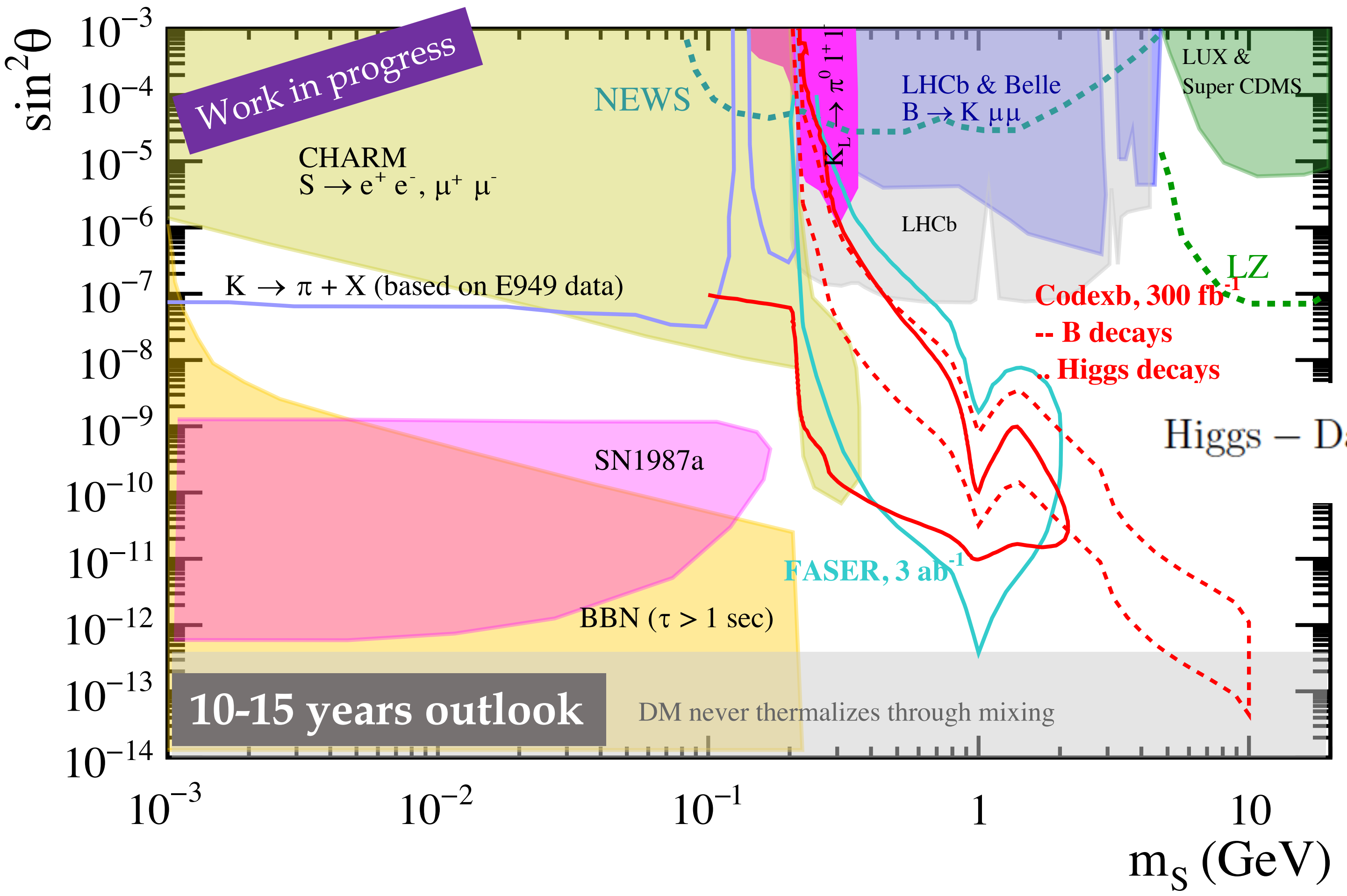


Higgs − Dark Scalar $\rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-, ..$

Dark Higgs, S $\quad (\mu S + \cancel{\lambda S^2})H^\dagger H$

BC 4

Light Dark Scalar mixing with the Higgs: PBC projects in 10-15 years



Higgs – Dark Scalar $\to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$

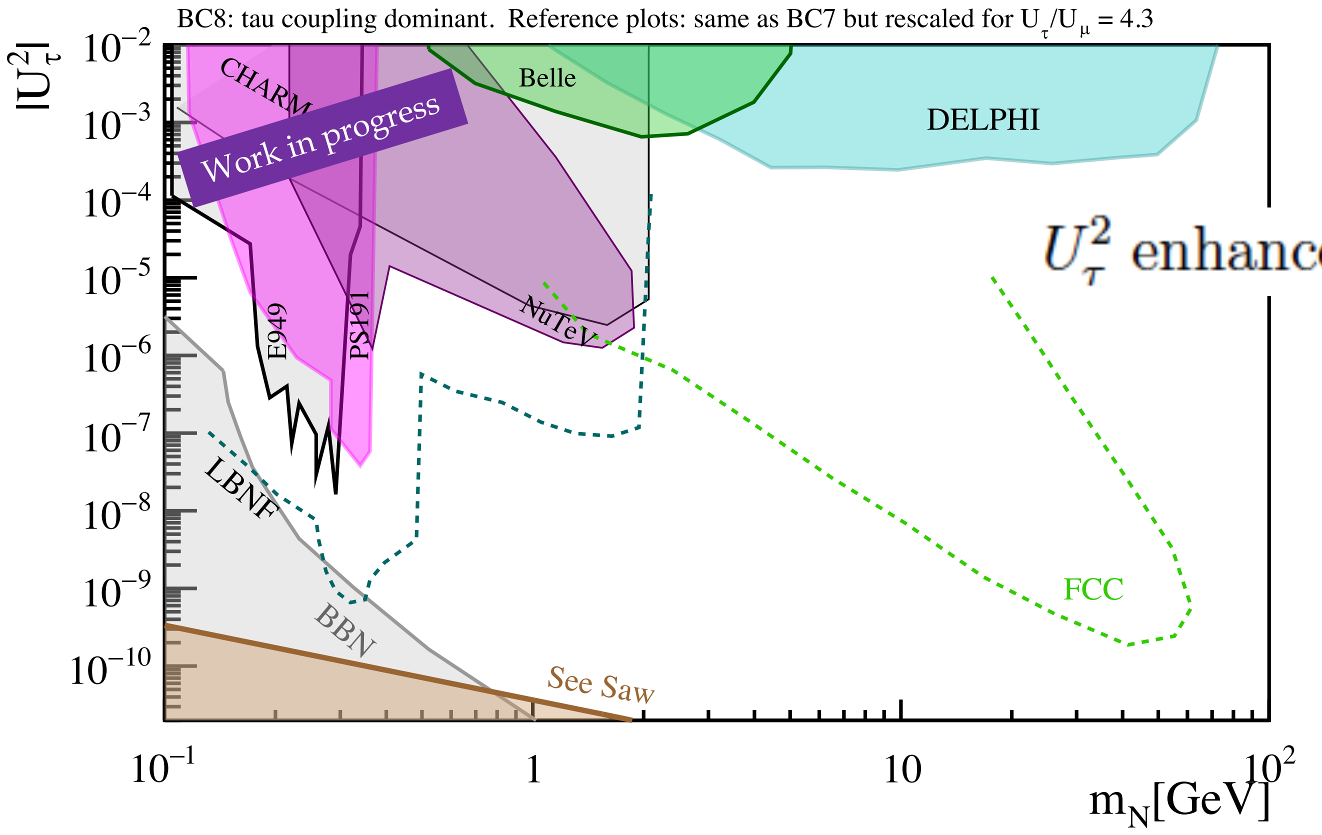
BC 5

Dark Higgs, $S \quad (\mu S + \lambda S^2) H^\dagger H$

Search for RH neutrinos below the EW scale

Portal	Coupling	Benchmark Cases.
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	BC1, BC2, BC3
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$	BC4, BC5
Axion, a	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu} \tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a} \overline{\psi} \gamma^\mu \gamma^5 \psi$	BC9, BC10, BC11
Sterile Neutrino, N	$y_N L H N$	BC6, BC7, BC8

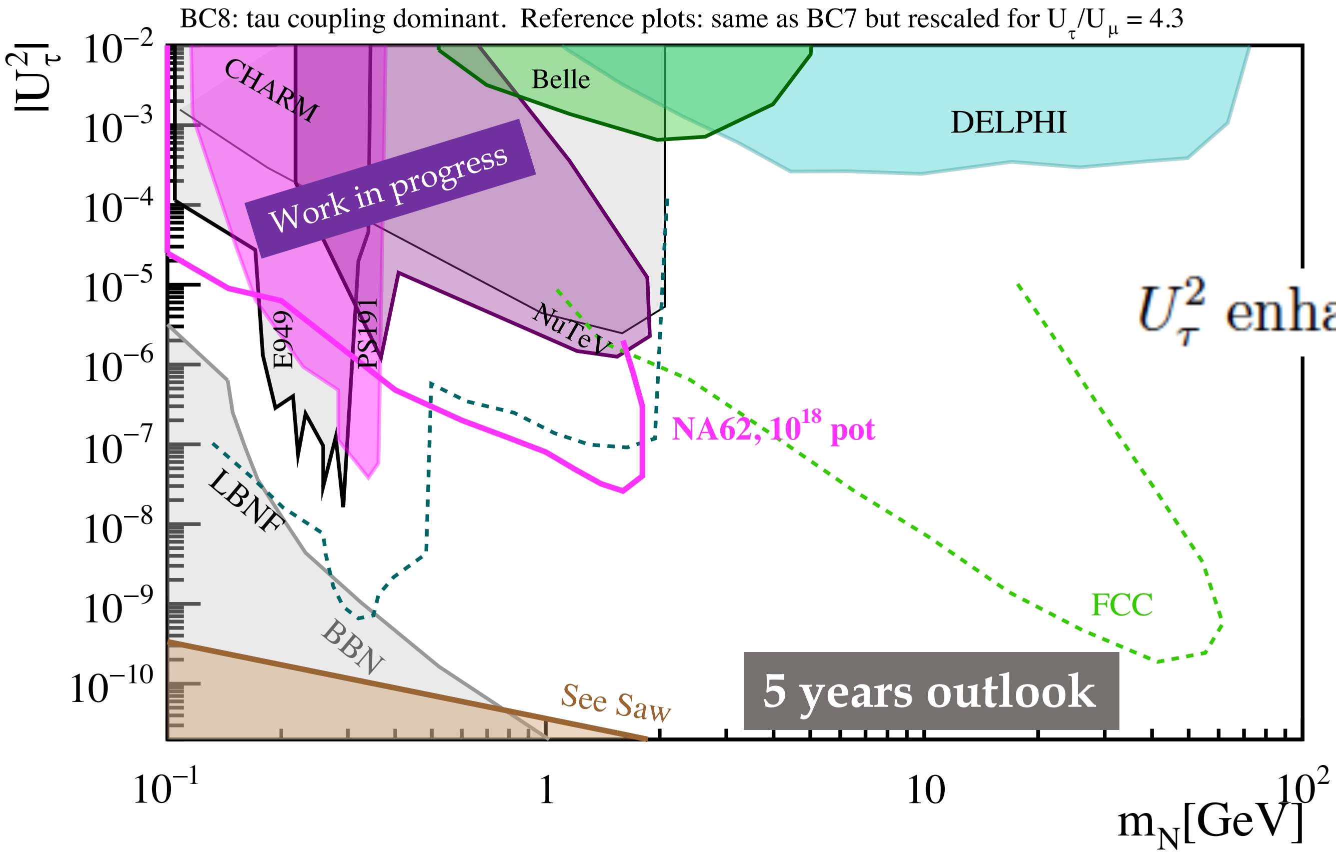
RH neutrinos below the EW scale: worldwide landscape



U_τ^2 enhanced

BC 8

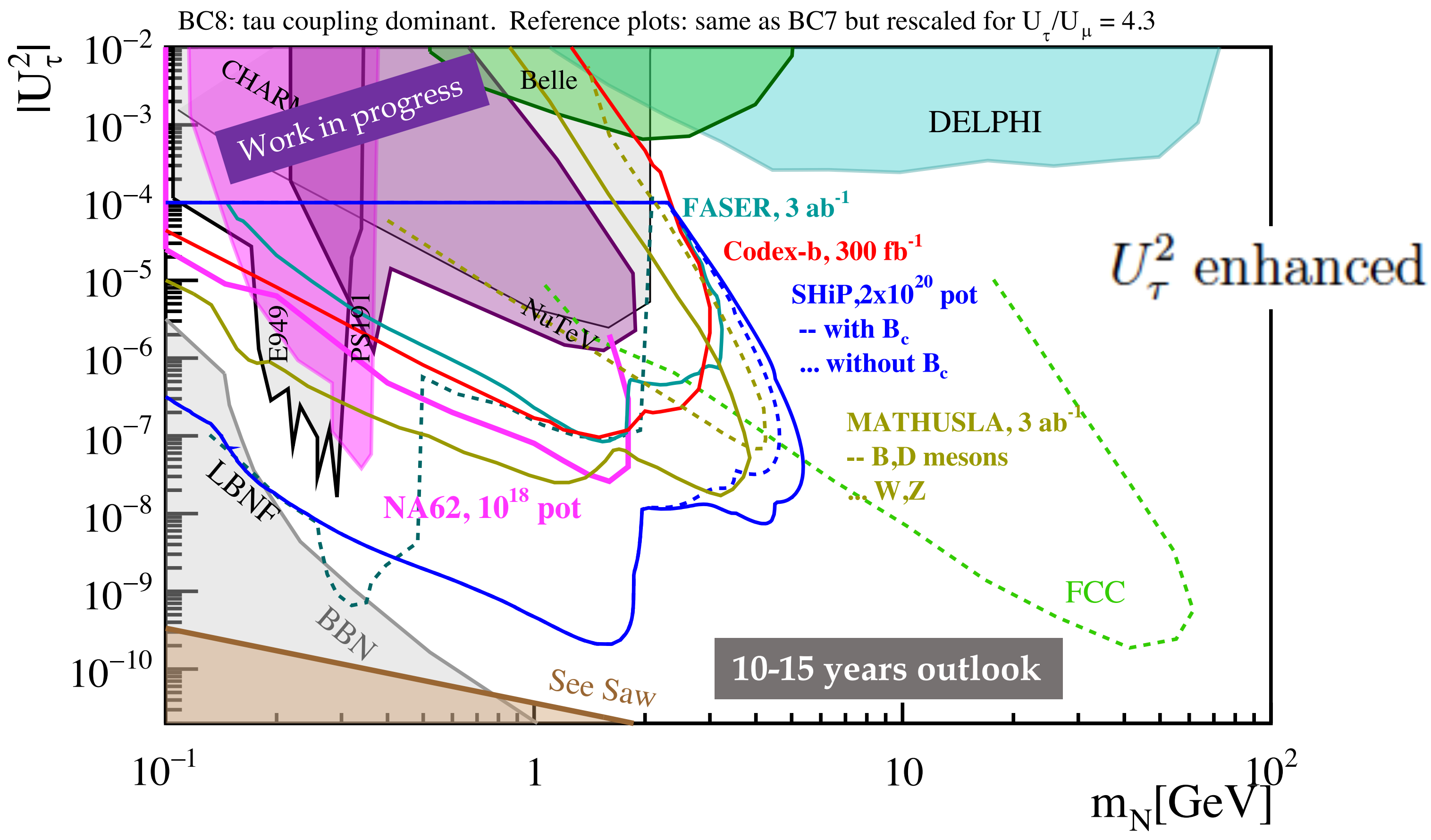
RH neutrinos below the EW scale: PBC projects in 5 years



U_τ^2 enhanced

BC 8

RH neutrinos below the EW scale: PBC projects in 10-15 years

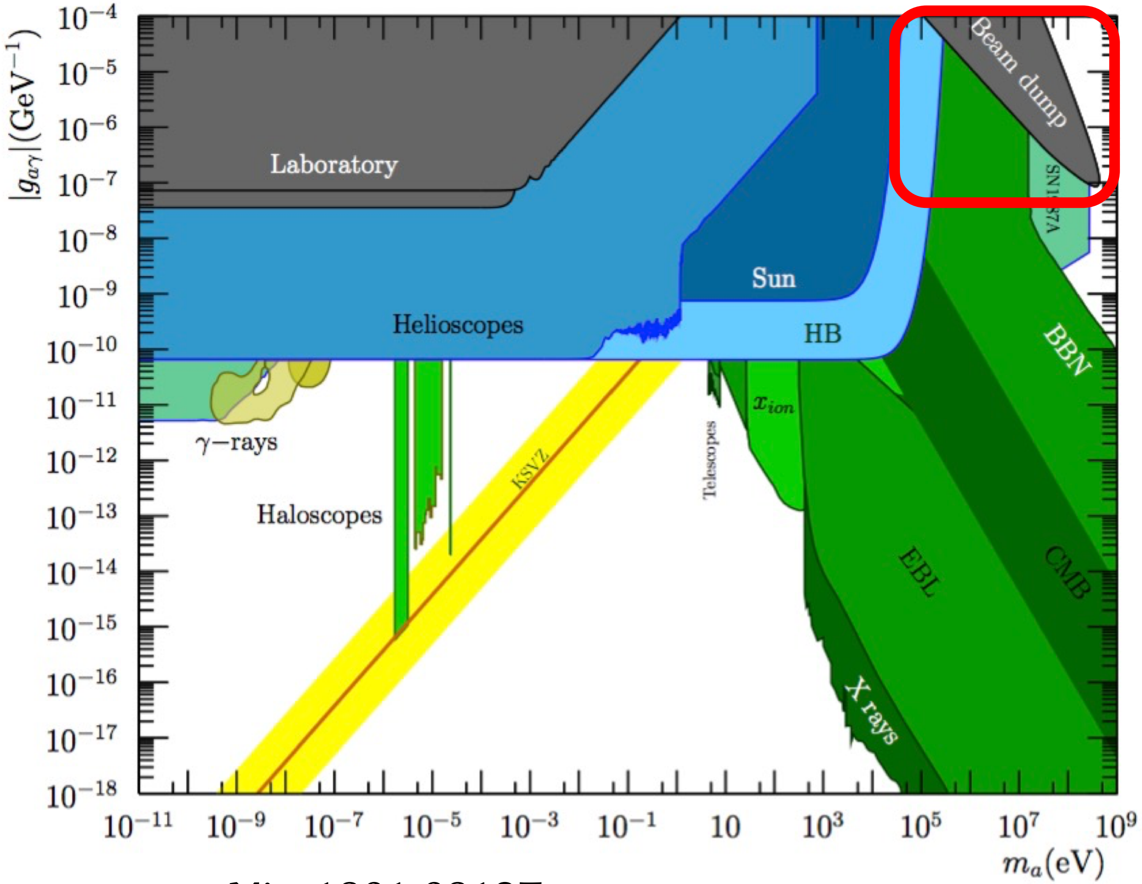


BC 8

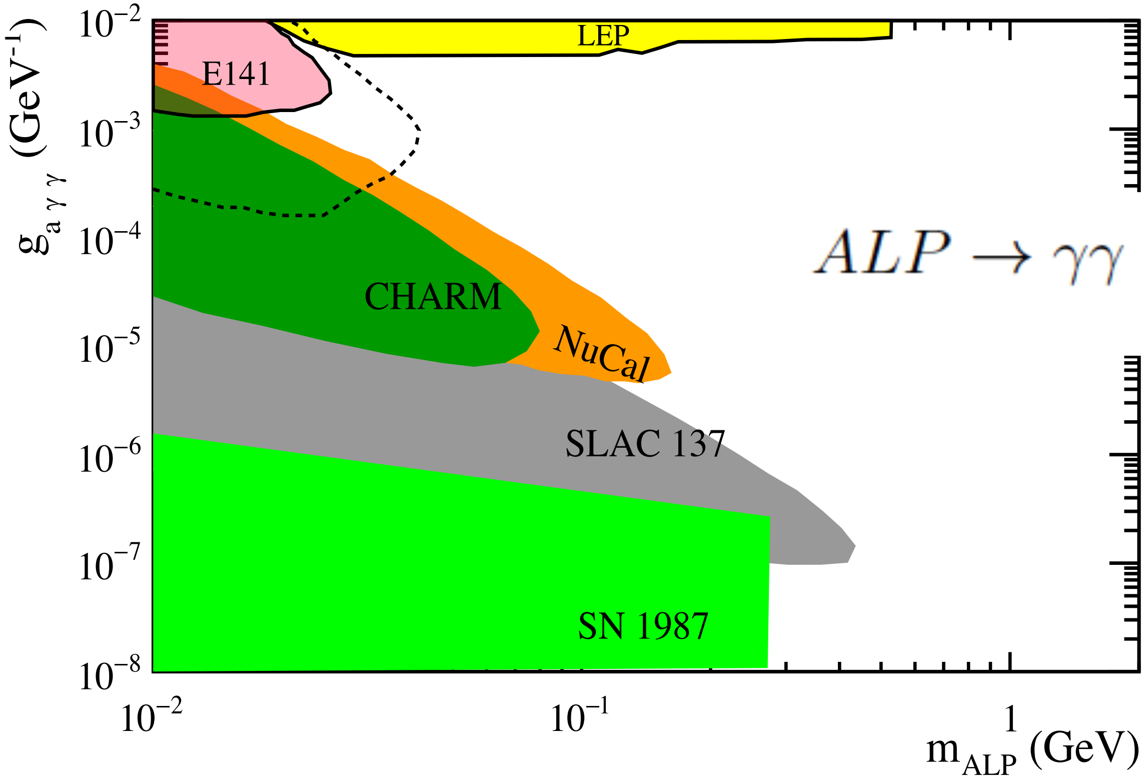
Search for axions and axion-like particles in the sub-eV mass range and to new sources of CPV in the >> TeV range

Portal	Coupling	**Benchmark Cases.**
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	**BC1, BC2, BC3**
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$	**BC4, BC5**
Axion, a	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$	**BC9, BC10, BC11**
Sterile Neutrino, N	$y_N LHN$	**BC6, BC7, BC8**

ALPS with photon coupling: worldwide landscape



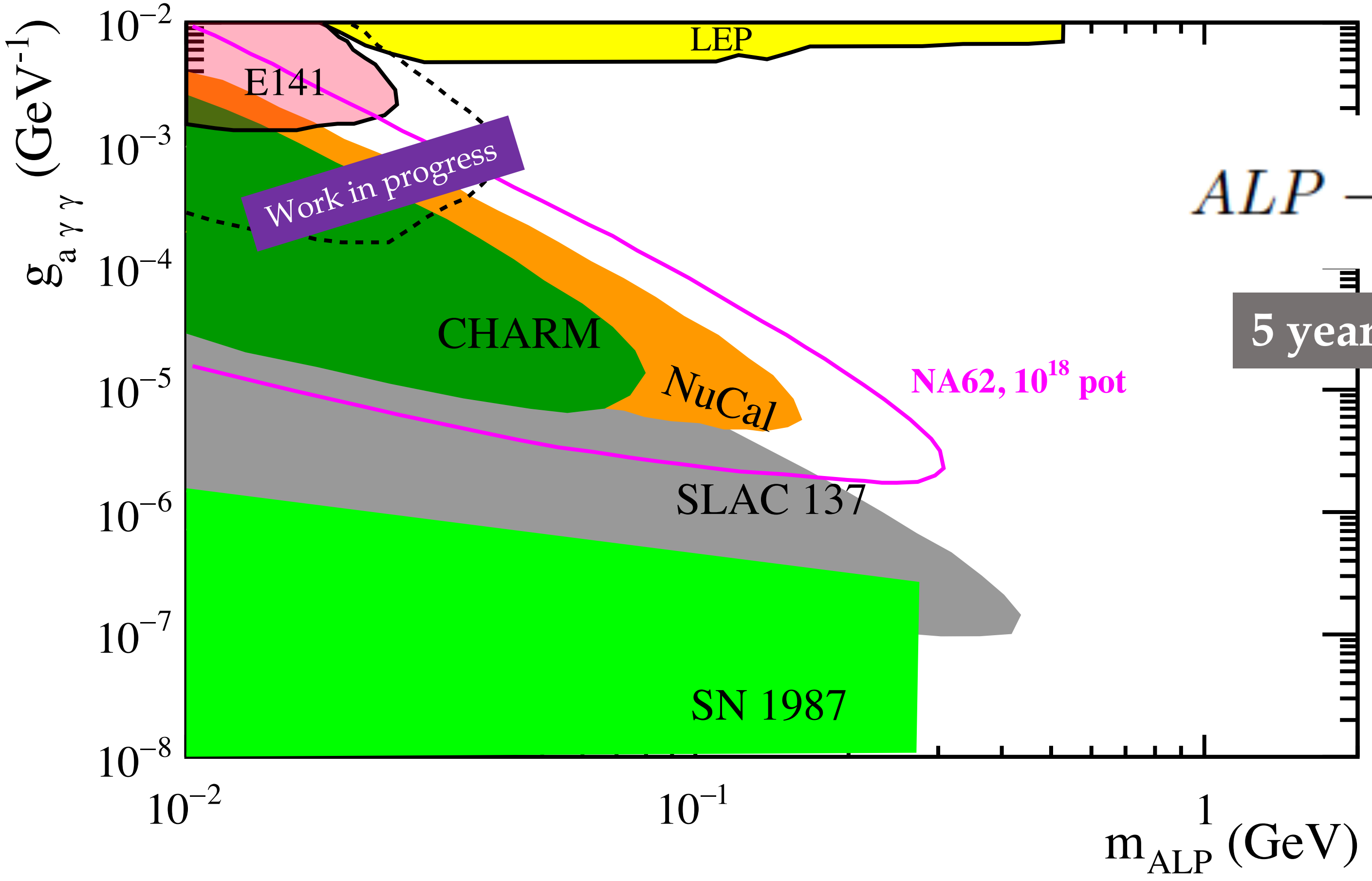
arXiv:1801.08127



axion, $ALP \to \gamma\gamma$

BC 9

ALPS with photon coupling: PBC projects in 5 years

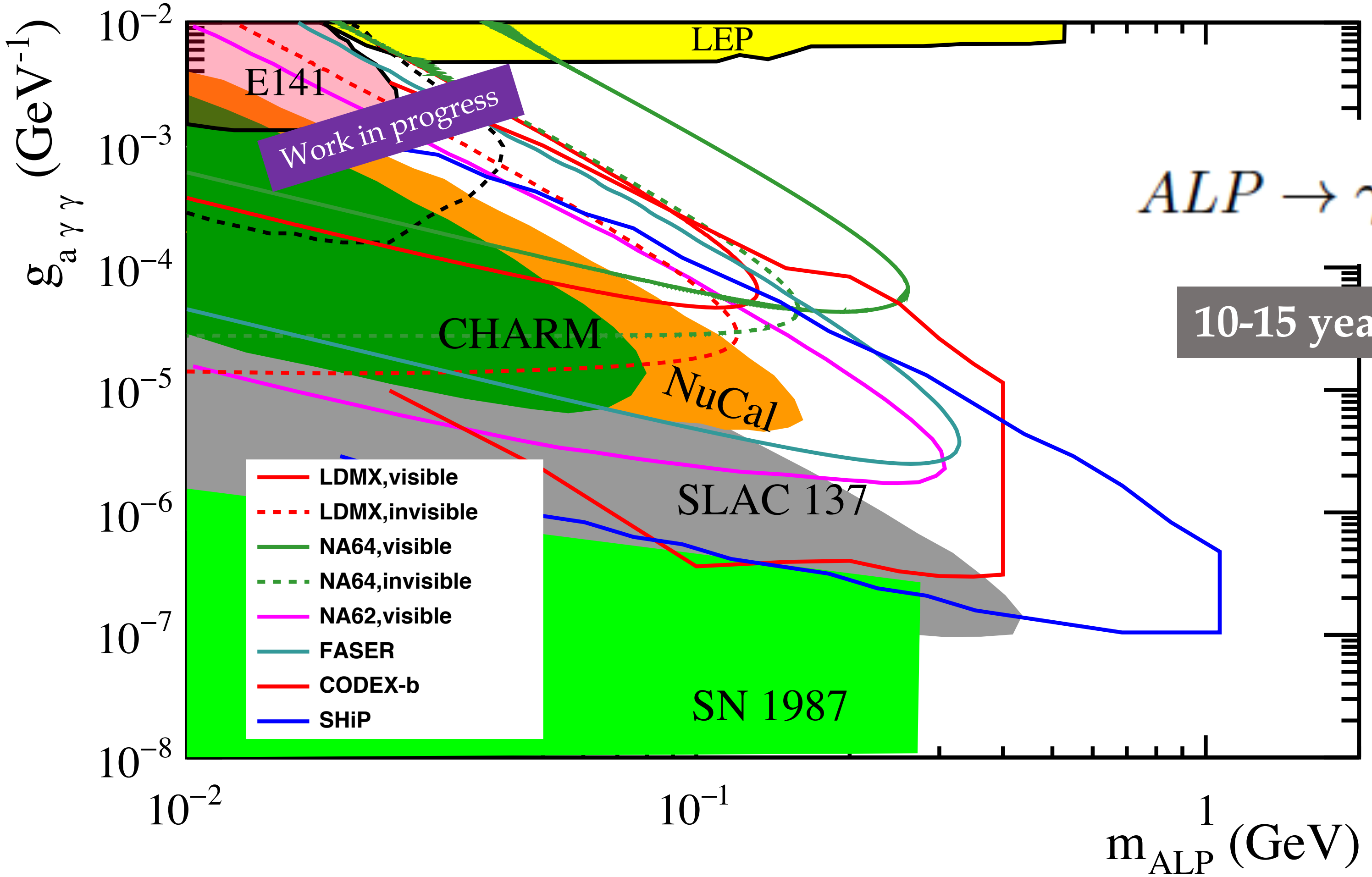


$ALP \rightarrow \gamma\gamma$, invisible

5 years outlook

BC 9

ALPS with photon coupling: PBC projects in 10-15 years

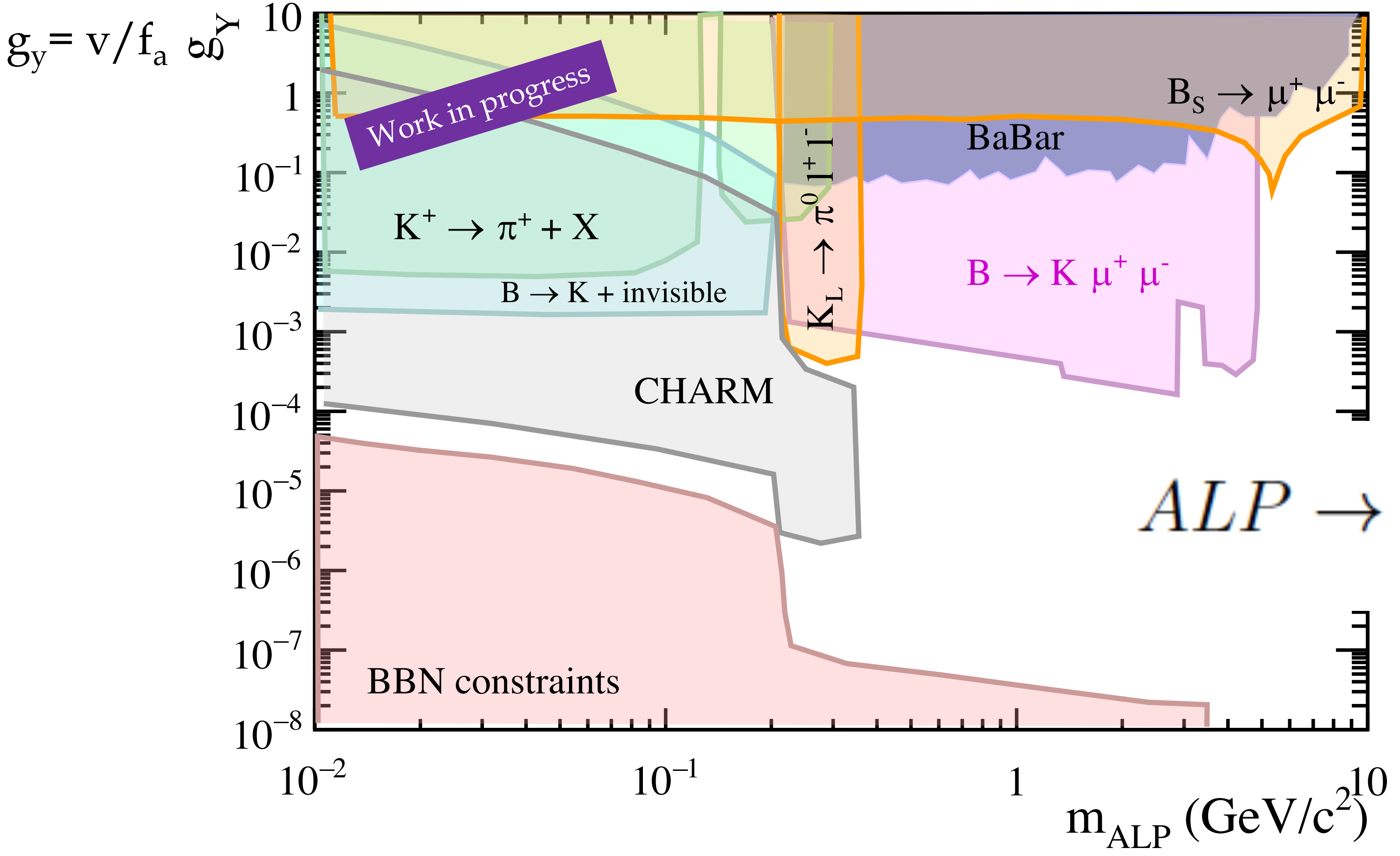


$ALP \to \gamma\gamma$, invisible

10-15 years outlook

BC 9

ALPS with fermion couplings: worldwide landscape

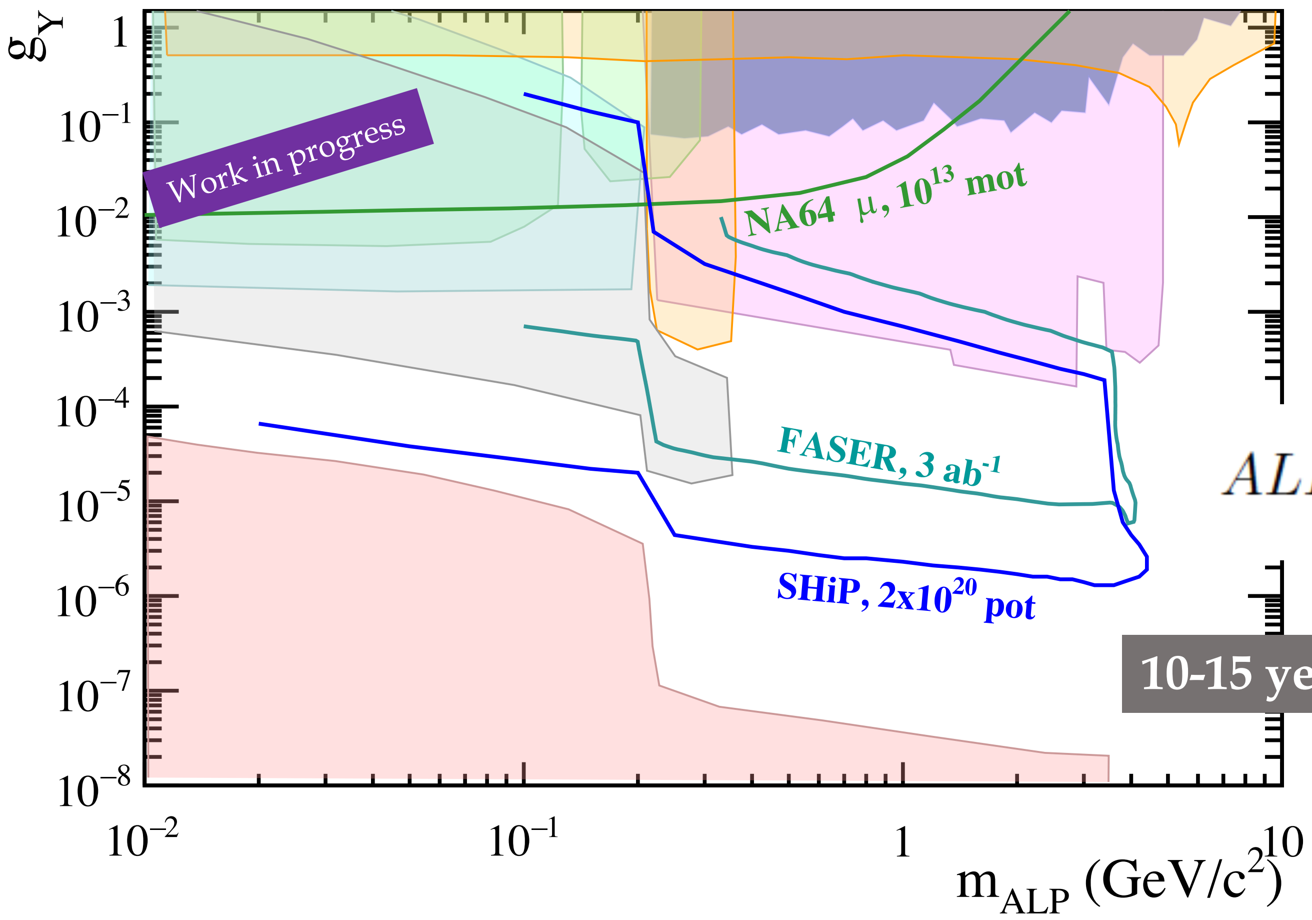


$$ALP \to f^+ f^-$$

BC 10

ALPS with fermion couplings: PBC projects in 10-15 years

$g_y = v/f_a$

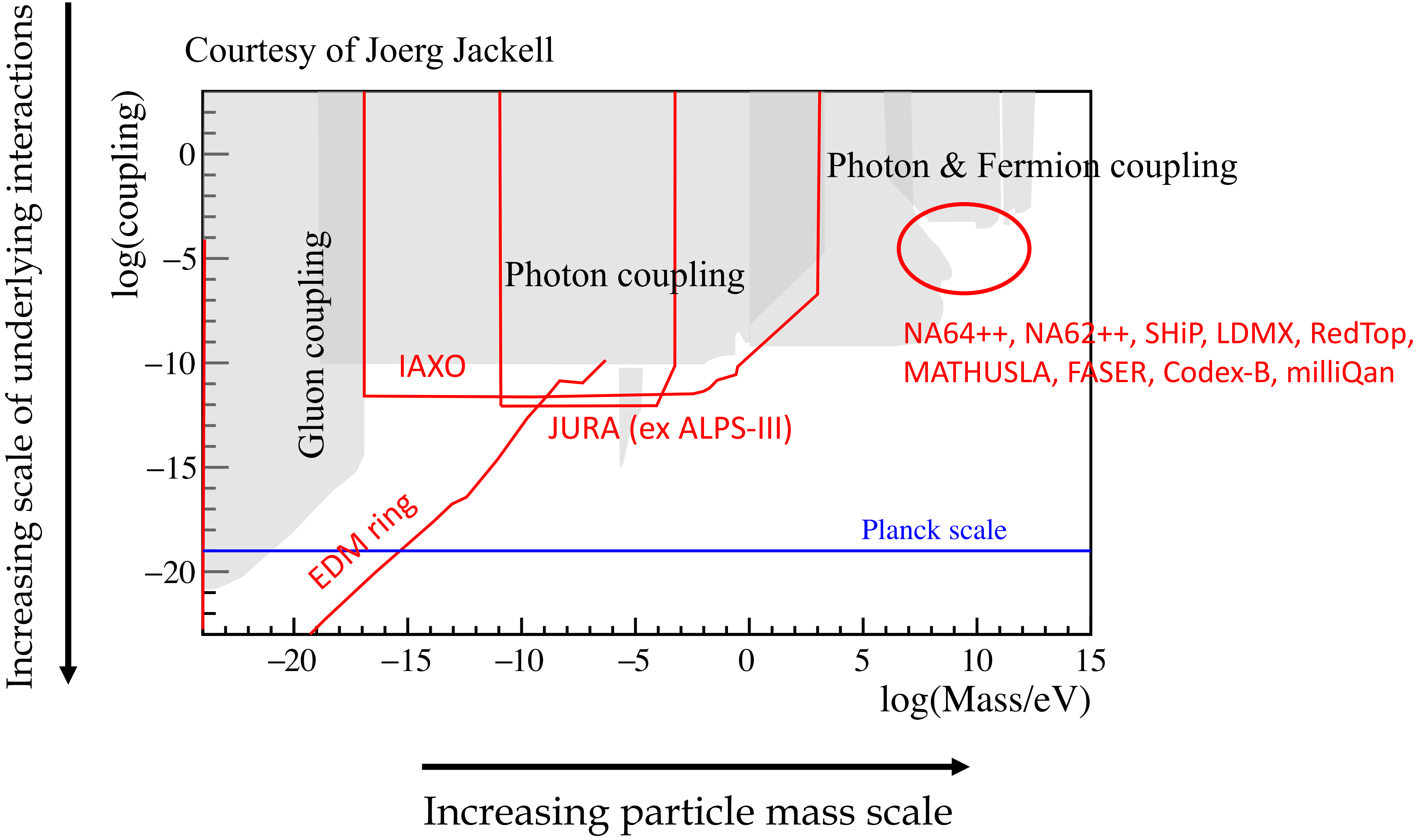


$ALP \to f^+ f^-$

BC 10

More sensitivity curves in preparation

Starting to quantify a comprehensive picture



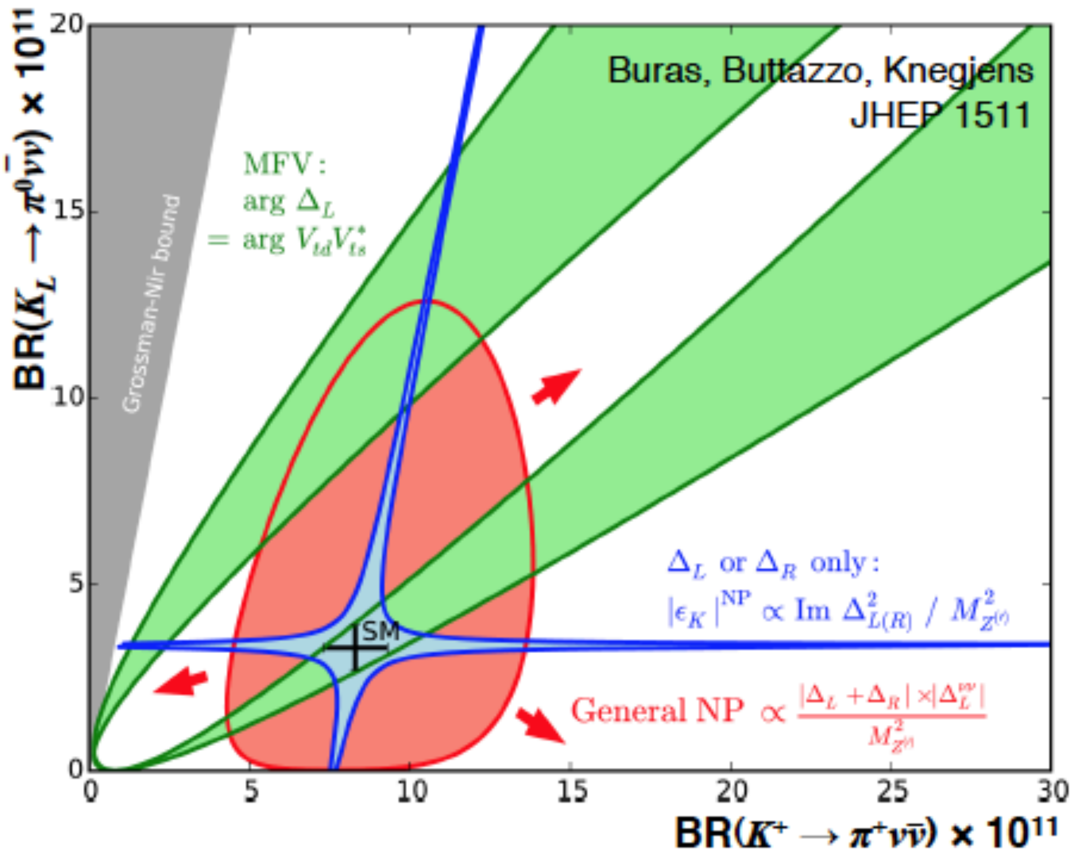
Projects considered in the BSM WG

Proposal	physics case	beam line	beam type	beam yield
sub-eV range:				
IAXO	axions/ALPs (photon coupling)	–	axions from sun	–
ALPS-III	axions/ALPs (photon coupling)	laboratory	LSW	–
CPEDM	p, d EDM,	EDM ring	p, d	–
	axions/ALPs (gluon coupling)		p, d	–
LHC-FT	charmed hadrons MDMs, EDMs	LHCb IP	7 TeV p	–
MeV-GeV range:				
SHiP	ALPs, Dark Photons,	BDF	400 GeV p	$2 \cdot 10^{20}$/5 years
	Dark Scalars, LDM, HNLs			
NA62^{++}	ALPs (photon, fermion coupling)	K12	400 GeV p	up to $3 \cdot 10^{18}$/year
	Dark Photons, Dark Scalars, HNLs			
NA64^{++}	ALPs (which couplings?)	H4	100 GeV e^-	$5 \cdot 10^{12}$ eot/year
	Dark Photons, Dark Scalars, LDM			
	$+ L_\mu - L_\tau$	M2	160 GeV μ	$10^{12} - 10^{13}$ mot/year
	+ CP, CPT, leptophobic DM	H2-H8, T9	$\sim$ 40 GeV π, K, p	$5 \cdot 10^{12}$/year
LDMX	Dark Photon, LDM, ALPs,...	eSPS	8 (SLAC) -16 (eSPS) GeV e^-	$10^{16} - 10^{18}$ eot/year
RedTop	Dark Photon, Dark scalar	CERN PS	1.8 or 3.5 GeV	10^{17} pot
MATHUSLA	Dark Scalar, Dark Photon, HNLs,..	ATLAS or CMS IP	14 TeV p	3000 fb^{-1}
FASER	Dark Photon, Dark Scalar, ALPs	ATLAS IP	14 TeV p	3000 fb^{-1}
MilliQan	milli charge	CMS IP	14 TeV p	300-3000 fb^{-1}
Codex-b	Dark Scalar, Dark Photons, ...	LHCb IP	14 TeV p	300 fb^{-1}
> TeV range:				
KLEVER	$K_L \to \pi^0 \nu \bar{\nu}$	P42	400 GeV p	$5 \cdot 10^{19}$ pot /5 years
TauFV	LFV τ decays	BDF	400 GeV p	5% of the SHiP yield

KLEVER @ K12: an experiment to measure $K_L \rightarrow \pi^0 \nu \nu$ branching fraction

Current status: $BR(K_L \rightarrow \pi^0 \nu \nu)$ (SM) = $(3.4 \pm 0.6)\ 10^{-11}$
$BR(K_L \rightarrow \pi^0 \nu \nu)$ (E391a) < $2.6\ 10^{-8}$ (90% CL)

New physics affects BRs differently for K^+ and K_L channels
Measurements of both can discriminate among NP scenarios



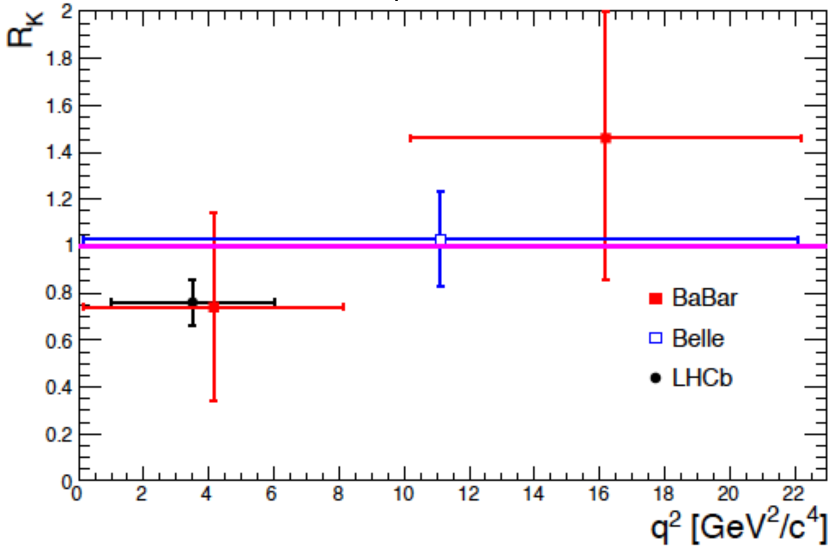
- Models with CKM-like flavor structure
  - Models with MFV
- Models with new flavor-violating interactions in which either LH or RH couplings dominate
  - *Z/Z'* models with pure LH/RH couplings
  - Littlest Higgs with *T* parity
- Models without above constraints
  - Randall-Sundrum

KLEVER @ K12: an experiment to measure $K_L \to \pi^0 \nu \nu$ branching fraction

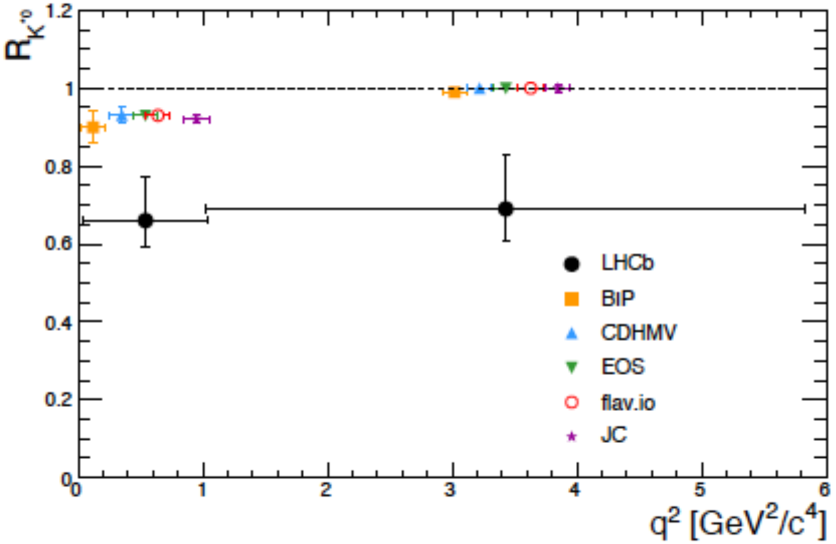
Current status: BR($K_L \to \pi^0 \nu \nu$) (SM) = (3.4 ±0.6) 10^{-11}
BR($K_L \to \pi^0 \nu \nu$) (E391a) < 2.6 10^{-8} (90% CL)

Connection with the B-anomalies

LHCb , Phys.Rev.Lett.113 151601 (2014)



LHCb, JHEP 08 055 (2017)



If the B anomalies are due to NP (Z′, leptoquarks, LFV processes in the third generation, etc.) the same NP can affect also the $K^+ \to \pi^+ \upsilon\upsilon$ and $K_L \to \pi^0\upsilon\upsilon$ branching fractions.

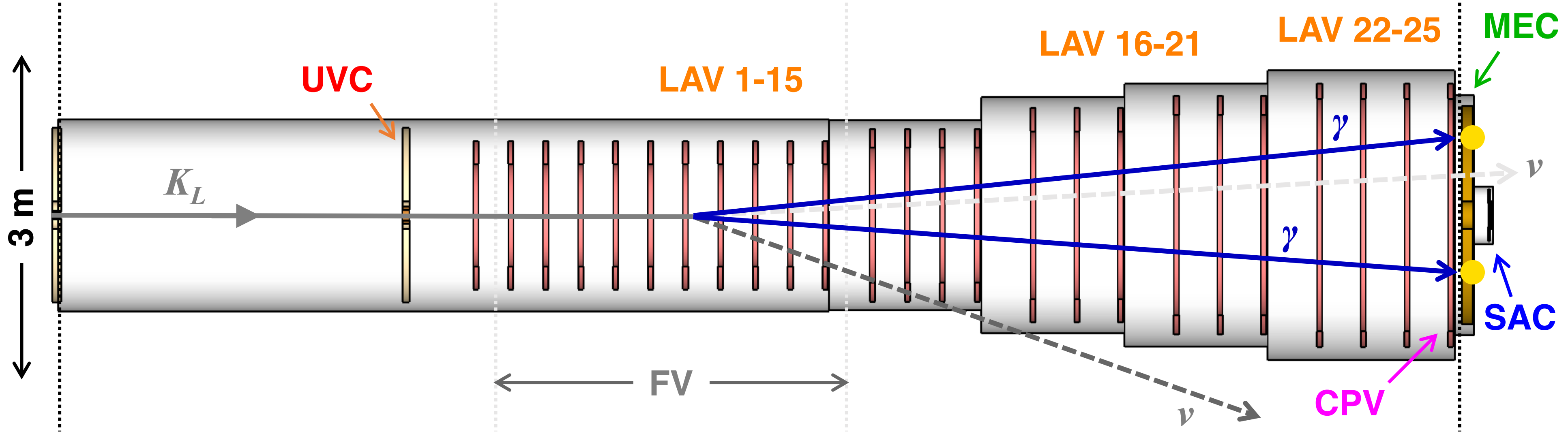
The quantitative effect is strongly model-dependent: in some models is similar in the two modes, in some others is suppressed/enhanced in the neutral mode with respect to the charged one.

However in any possible NP scenario, for both modes, precision is key.

KLEVER @ K12: an experiment to measure $K_L \to \pi^0 \nu \nu$ branching fraction

10^{19} pot/yr × 5 years → 2 × 10^{13} ppp/16.8s = 6× increase relative to NA62

Feasibility/cost study a primary goal of our involvement in Conventional Beam WG



KLEVER target sensitivity:
5 years starting in Run 4
~ 60 SM $K_L \to \pi^0 \nu\nu$ with S/B ~ 1, hence precision of 20% on the BR
Competition:
KOTO (JPARC) expects to reach SM sensitivity in 2021
Strong intention to integrate o(100) events with a major upgrade of line and detector but no official proposal yet.

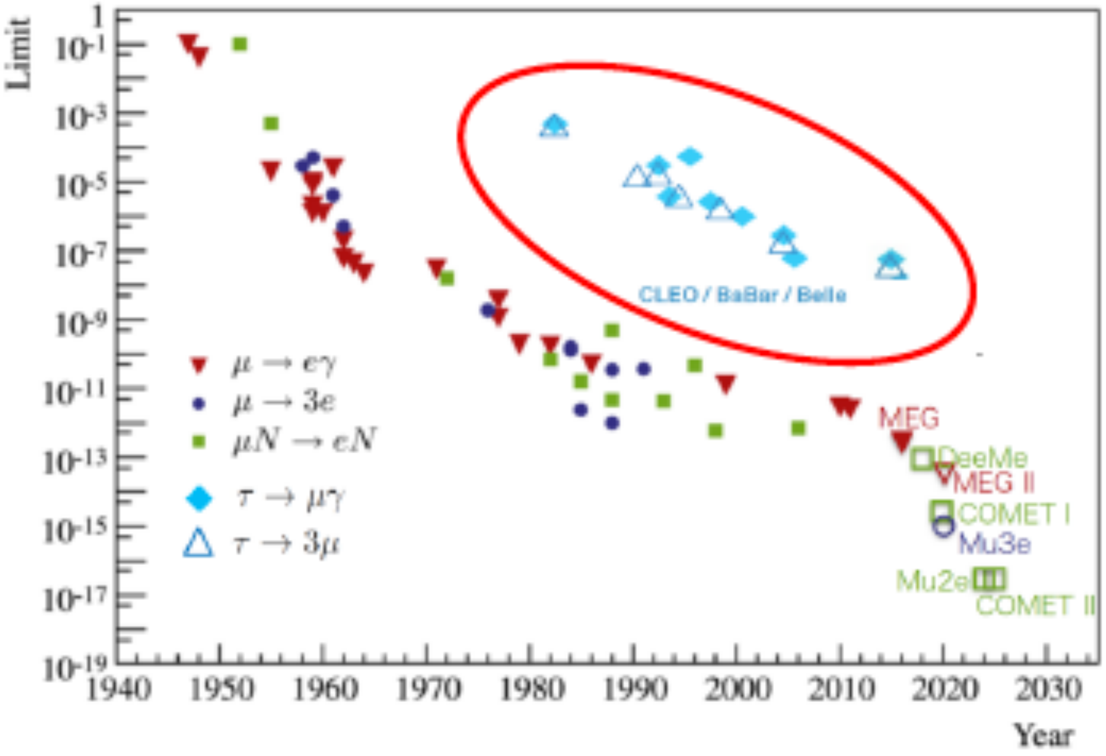
TauFV @ BDF: LFV tau decays

Long-standing, and well motivated (particularly since the discovery of neutrino oscillations) programme of searches for charged Lepton Flavour Violation.

Let's take $\tau \to \mu\mu\mu$ as benchmark mode. Current best 90 % CL limits:

Belle	2.1 x 10^{-8}	[PLB 687 (2010) 139]
BaBar	3.3 x 10^{-8}	[PRD 81 (2010) 111101]
LHCb	4.6 x 10^{-8}	[JHEP 02 (2015) 121]

Most improvement in coming decade is expected from Belle II, who aim for 1 x 10^{-9} [arXiv:1011.0352] and may do better if they achieve zero background.

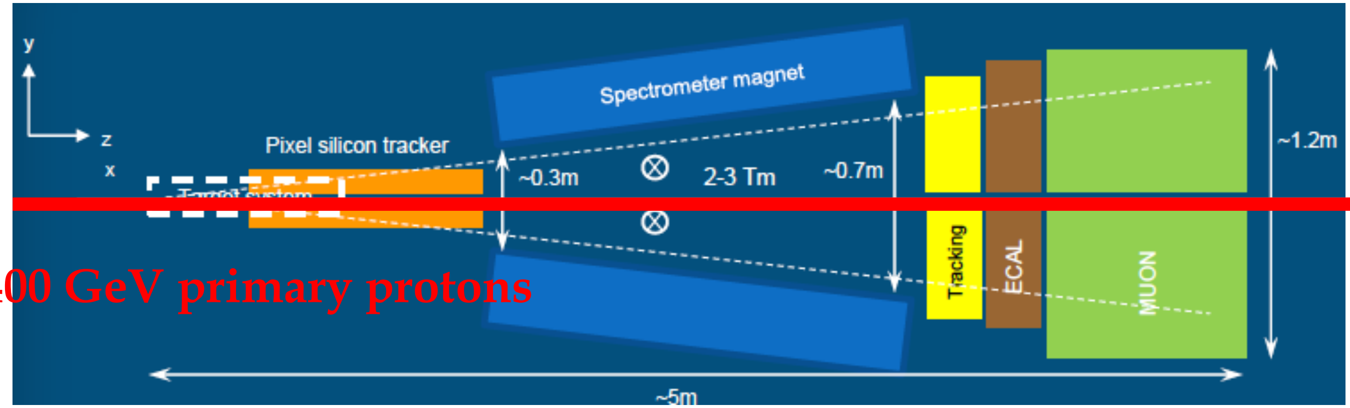


Study of tau LFV decays very timely, also in connection with the B anomalies.
Complement the quest for new physics in other cLFV modes, as mu2e @ FNAL and mu3e @ PSI.

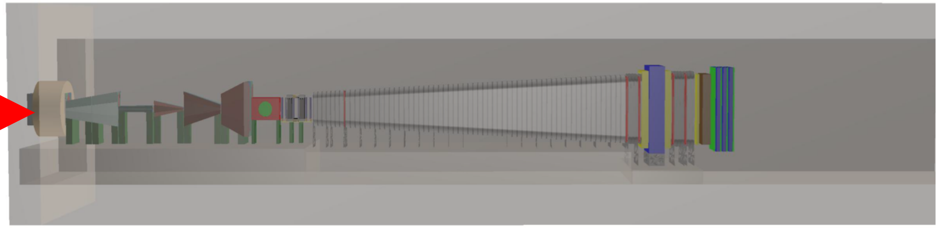
TauFV @ BDF: LFV tau decays

TauFV proposed to be located into the BDF line upstream of SHiP. Use ~2% of protons hitting on (probably) a wire target to study LFV decays of tau leptons.

TauFV



SHiP



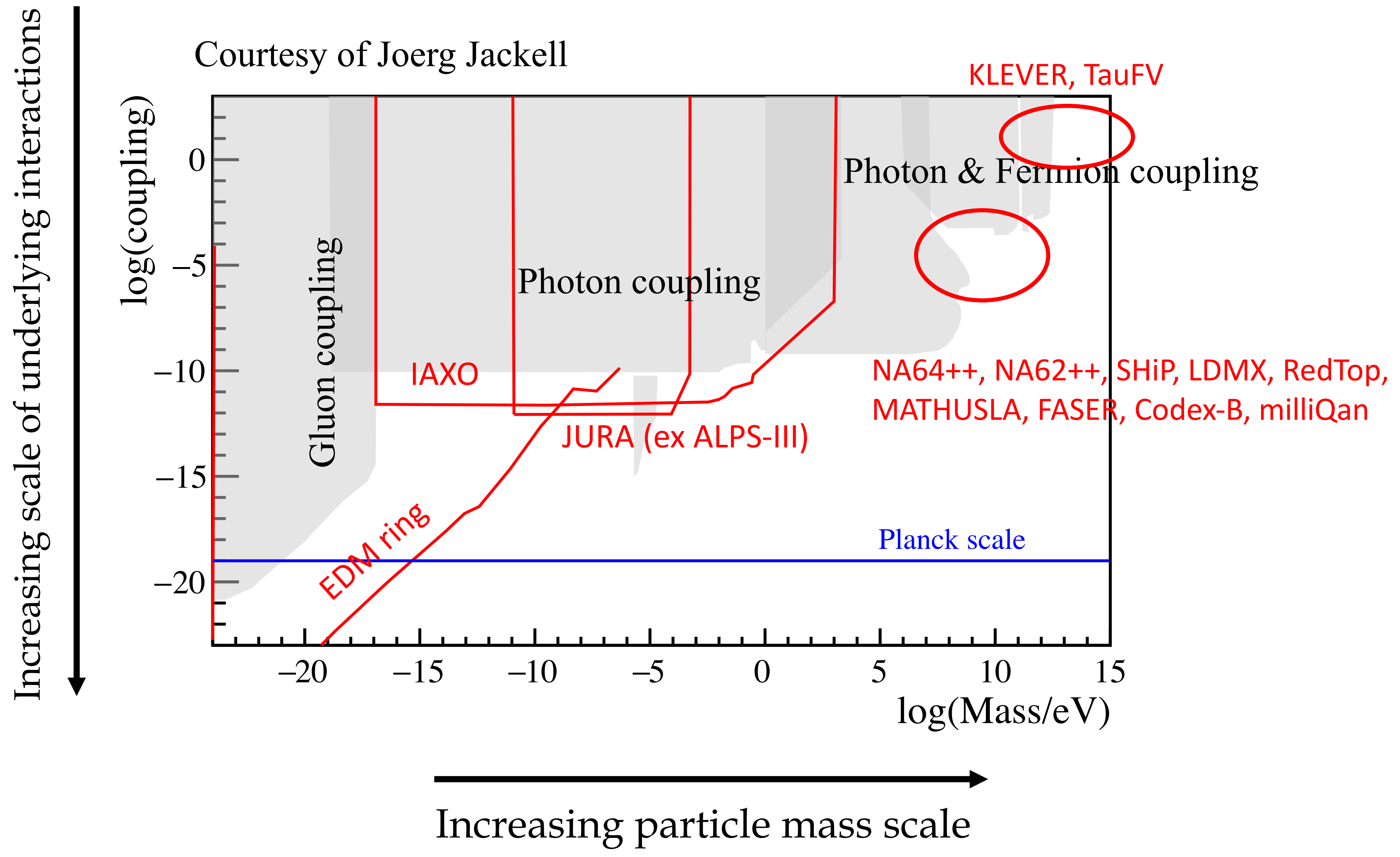
not to scale

Profit of the higher signal yield than at any other facility:

Eg: $\tau \longrightarrow \mu\mu\mu$ yield assuming a BR ~ 10^{-9}

Future experiment	Yield	Extrapolated from
TauFV (4 x 10^{18} PoT)	8000	Numbers on this slide
Belle II (50 ab^{-1})	9	PLB 687 (2010) 139
LHCb Upgrade I (50 fb^{-1})	140	JHEP 02 (2015) 121
LHCb Upgrade II (300 fb^{-1})	840	ditto

Starting to quantify a comprehensive picture



Conclusions

- The target of the PBC activity at CERN is a broad, rich and compelling physics programme which addresses the open questions of particle physics in a way complementary to the LHC and other initiatives in the world (eg DM direct detection).

- This programme aims to exploit the unique CERN scientific infrastructure and accelerator complex in a timescale of 5-15 years.

- A large and lively community with several different scientific proposals is growing at CERN and now is starting to speak a common language, to collaborate and to work in a coherent way.

- A preliminary set of comparative plots, based on theoretically and phenomenologically motivated models, shows us the scientific potential and the impact that CERN could have in the coming years in the quest for NP in the sub-eV, MeV-GeV and ultra-TeV scales.

- The projects presented in the PBC framework could be a very attractive option while preparing the next big machine.

- Several documents are in preparation for the next update of the ESPP.

Physics Beyond Colliders

Thank you for your attention.

SPARES

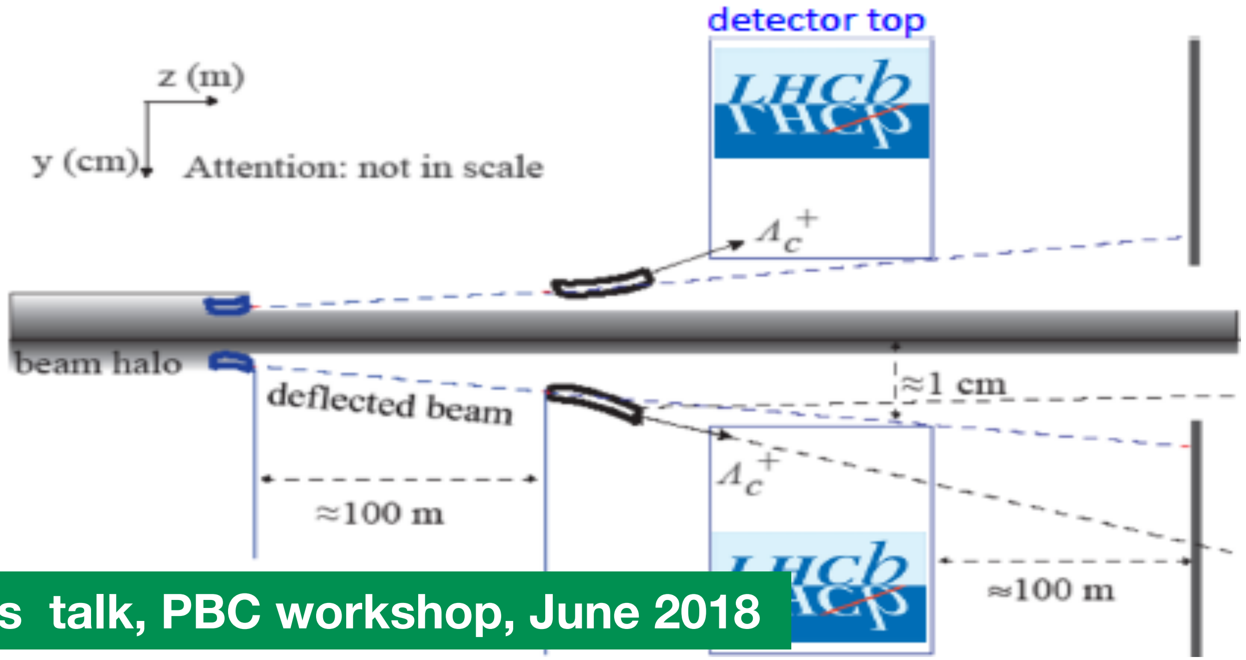
EDMs in charmed hadrons: LHC-FT

EDM searches in different systems are complementary to disentangle the underlying source of CPV.
Charmed hadrons EDMs predicted to be ~ 10^{-32} e cm in SM (EPJC 77 (2017) 102.
If CP is broken maximally by some "unspecified" strong interactions
at a scale ~ 1-10 TeV that also do not respect chiral symmetry, then:

$d \sim e\, v_{EW} / \Lambda^2 \sim$ starts at $(10^{-17} - 10^{-18})$ e cm

If democratic among families – then of course excluded. "Needs" a model that emphasizes charm quark.

- If perturbative: $x \sim 10^{-2}$, down to $(10^{-19} - 10^{-20})$ e cm level and below.
- If respecting chiral dynamics: $x\, y_c \sim 10^{-2}$, down to 10^{-22} e cm



Use deflected beam halo to W target followed by a second bent crystal. Measure s_x component of the spin precession in the E of the crystal

See S. Radaelli's talk, PBC workshop, June 2018

ALPS3 – a next generation LSW

- ALPS3 is a foreseen project to be explored as a next generation experiment with respect to ALPS2
- ALPS2 will reach state of the art for the optical component in a LSW **resonant regeneration experiment** with 100 + 100 m resonant cavities
- ALPS3 will eventually embed newly developed CERN magnet to push the sensitivity of ALPS3
- The BSM subgroup follows the progress of ALPS2