PBC-BSM Working Group Report

Gaia Lanfranchi – CERN & INFN

on behalf of the PBC-BSM coordinators
(C. Burrage, K. Jungmann, GL, K. Kirch, M. Pospelov, A. Rozanov, G. Ruoso)

based on **CERN-PBC-REPORT-2018-007**

Physics Beyond Colliders Workshop – January 2019

The PBC(–BSM WG) mandate

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

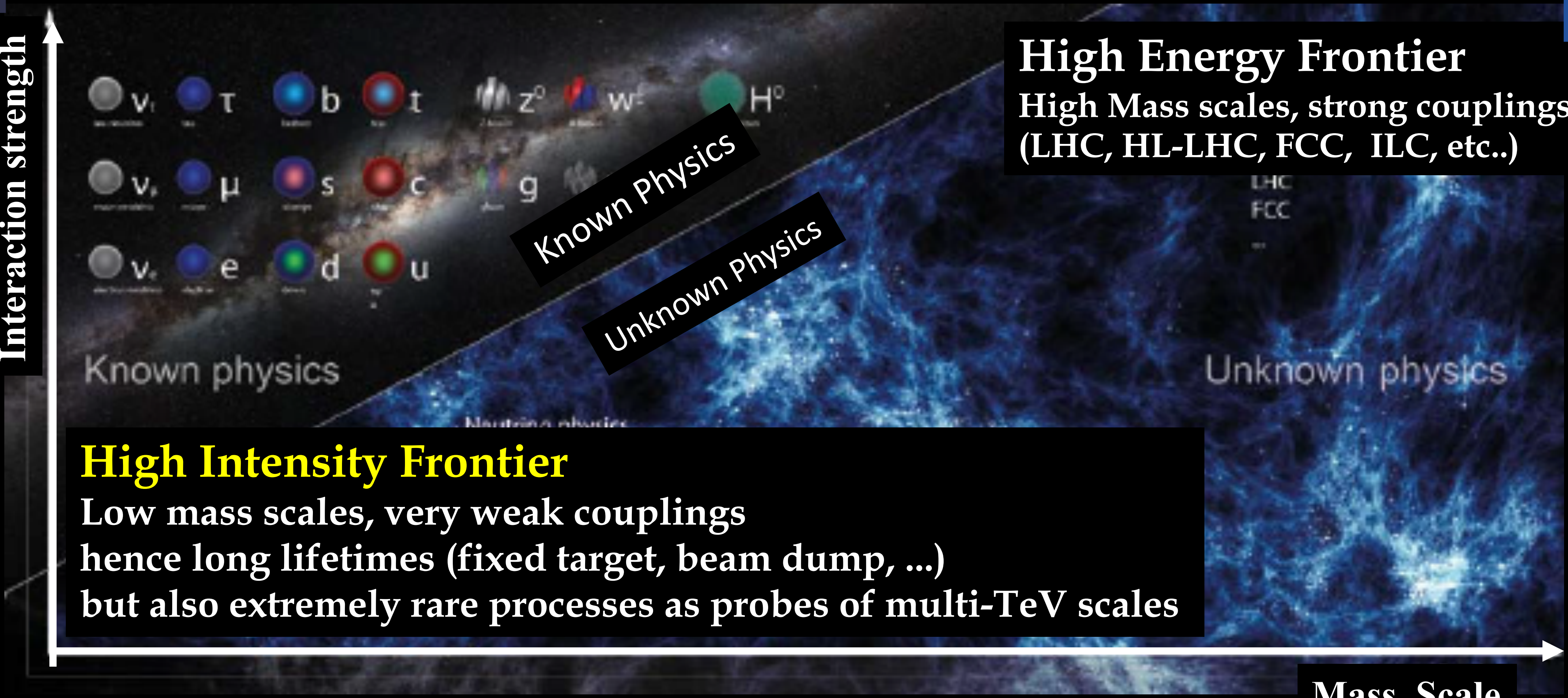
Mandate

"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."

Some outstanding fundamental open questions in particle physics:

- Origin of the neutrino masses and oscillations
- Nature of Dark Matter
- Mechanism of Baryogenesis

Physics Targets of the PBC-BSM WG



High Energy Frontier

High Mass scales, strong couplings
(LHC, HL-LHC, FCC, ILC, etc..)

High Intensity Frontier

Low mass scales, very weak couplings
hence long lifetimes (fixed target, beam dump, ...)
but also extremely rare processes as probes of multi-TeV scales

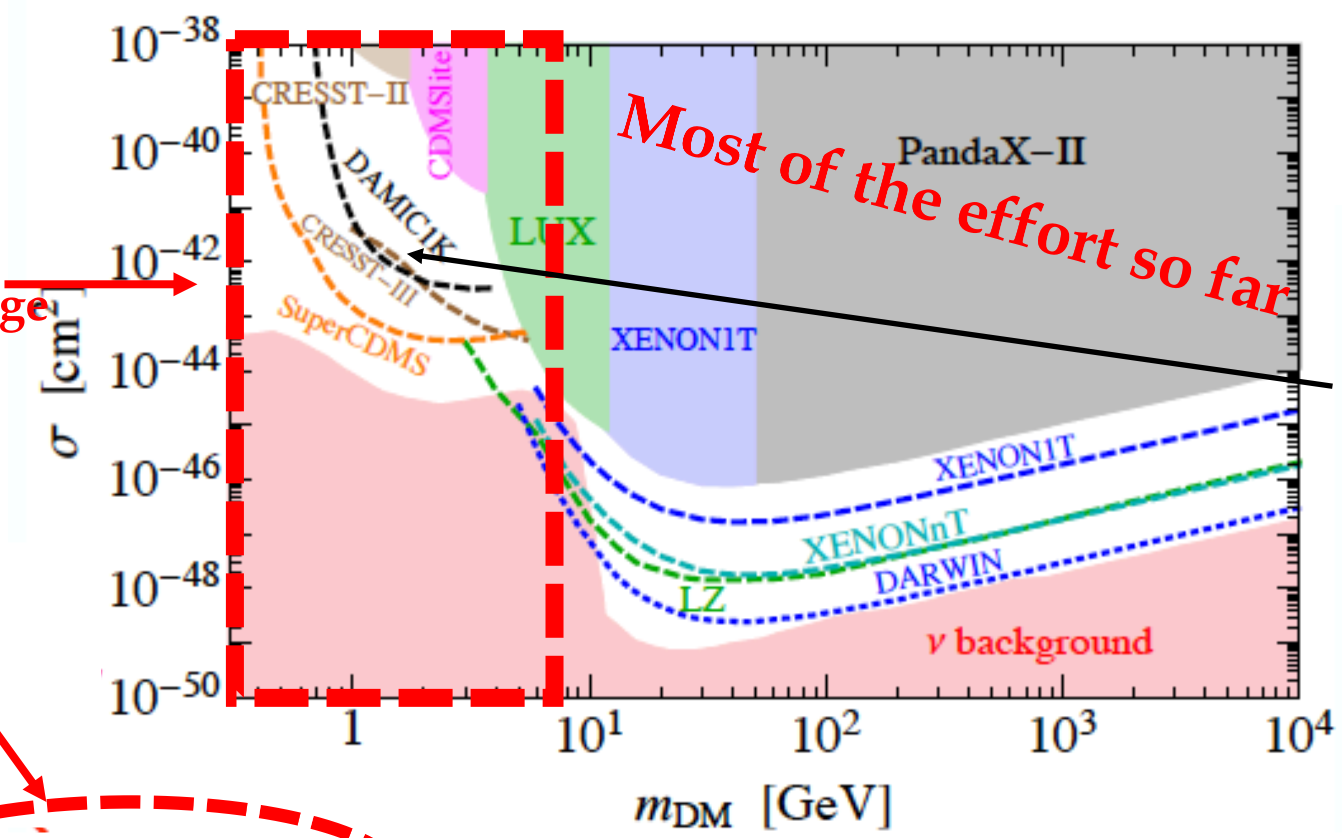
Many TeV-scale ideas/models have been scrutinized
Need a systematic approach for the high intensity frontier:
main target of the PBC-BSM activity

PBC target: (Light) Dark Matter with thermal origin

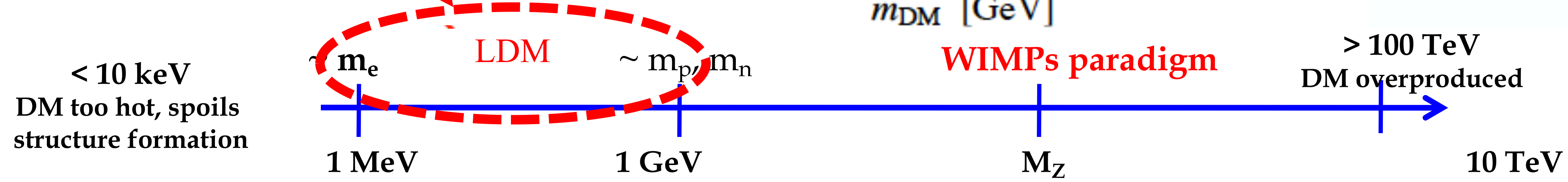
DM candidates with thermal origin can have mass between 10 keV and 100 TeV.

New Particles with
masses in the MeV-GeV range
and very weakly coupled
to light mediators

PBC-BSM target



Increasing interest also in the DM direct detection community (lively and growing field)



PBC target: (Light) Right-Handed Neutrinos

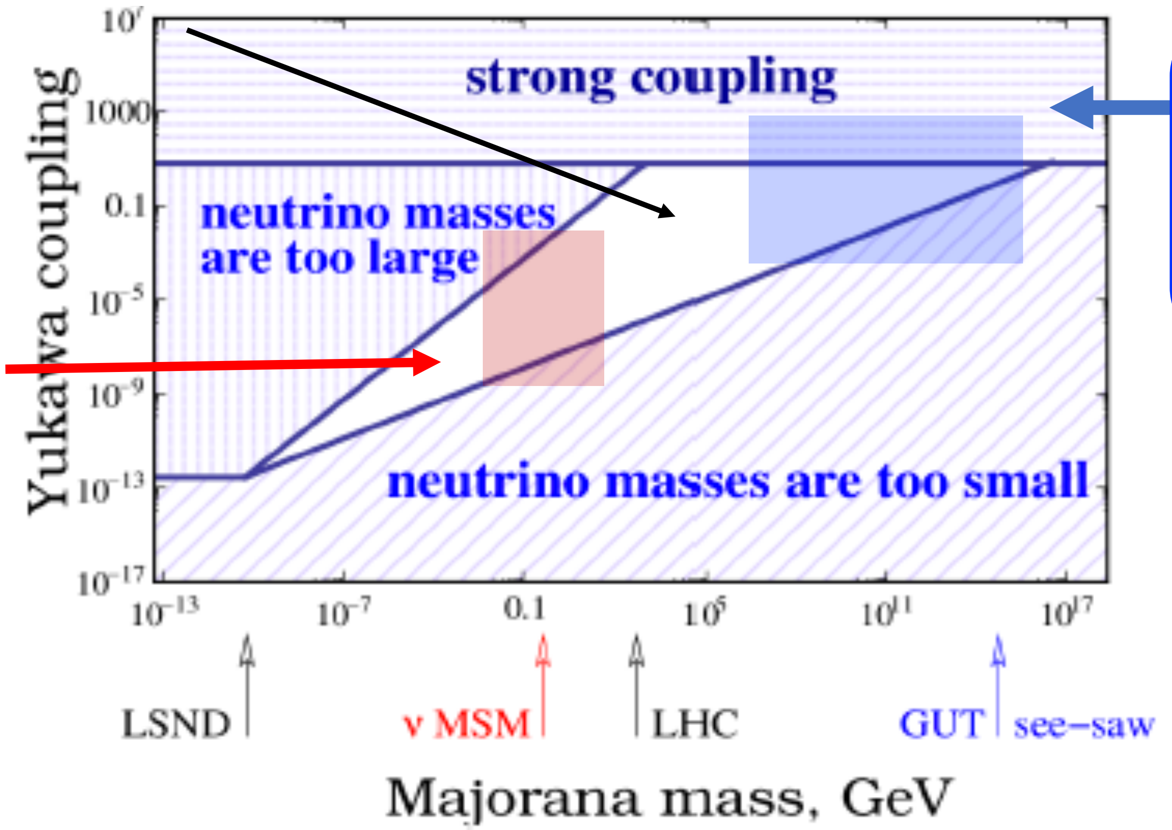
Neutrino portal extensions of the SM is motivated by the neutrino mass generation mechanism.
It is also motivated by cosmology: couplings between Right-Handed neutrinos can violate CP and generate matter-anti matter asymmetry in the early Universe.

Right handed neutrinos responsible of the see-saw mechanism can have any coupling/mass in the white area.

Alternative choice: EW see-saw (νMSM)

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

PBC target



Popular choice: GUT see-saw

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

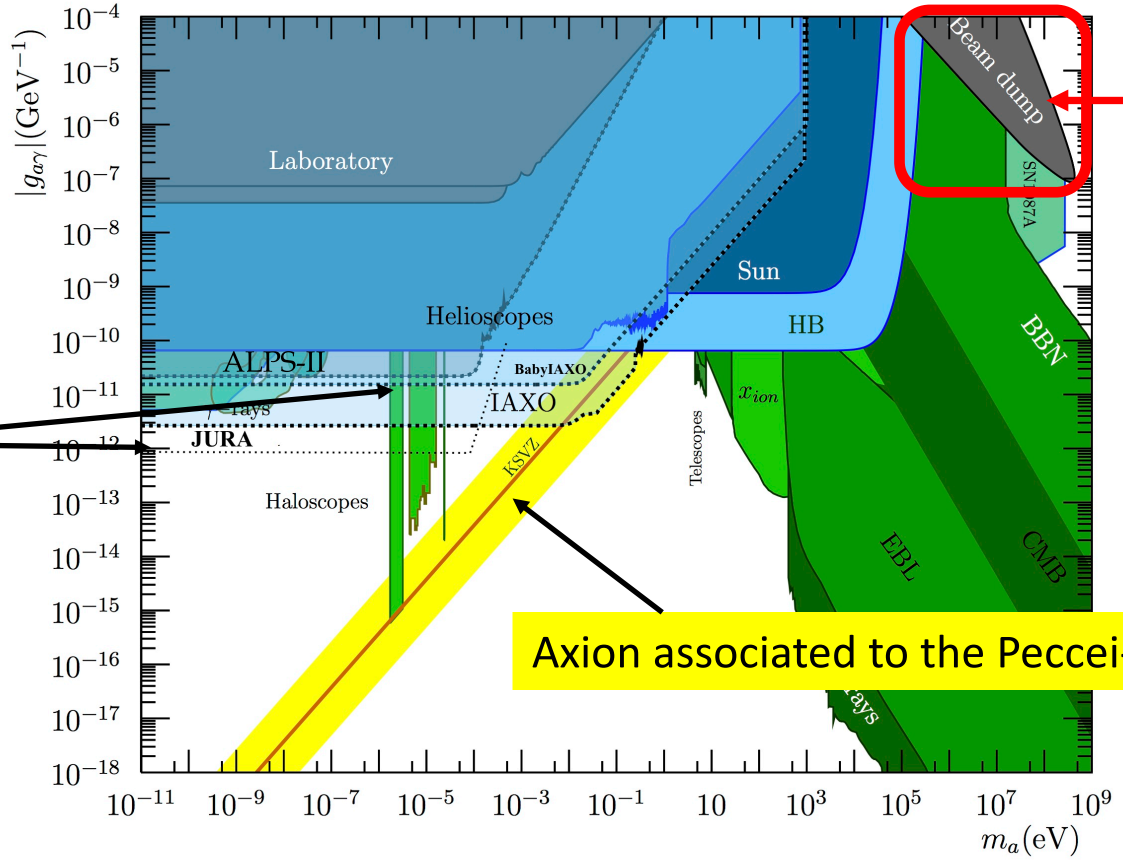
PBC target: Axion and Axion-Like Particles

Axion = Pseudo-Nambu Goldstone Boson associated to Peccei-Quinn symmetry, a global U(1), introduced to address the Strong QCD problem. Vast range of masses and couplings possible, with fixed relation.

Axion-Like Particle (ALP): a generalized version of the axion (at the cost of the original motivation from the strong CP problem). No direct relation between coupling and mass.

Axions and ALPs in the sub-eV mass range (lively and well-established community)

PBC target



Axion associated to the Peccei-Quinn symmetry

Interest to explore the MeV-GeV region at accelerator-based experiments

PBC target

BSM Experimental Proposals and Physics Programme

About 15 proposals have been considered in the BSM WG so far.
Since the TeV scale is very well explored at the LHC, focus on the sub-eV, MeV-GeV and multi-TeV scales:

sub-eV NP :
Axions with helioscopes, LSW and EDM rings

MeV-GeV NP:
Hidden Sector at accelerator-based experiments

Multi-TeV NP:
Ultra-rare/forbidden decays, EDM ring.

Proposal	Main Physics Cases	Beam Line	Beam Type	Beam Yield
sub-eV mass range:				
IAXO	axions/ALPs (photon coupling)	–	axions from sun	–
JURA	axions/ALPs (photon coupling)	laboratory	LSW	–
CPEDM	p, d oEDMs	EDM ring	p, d	–
	axions/ALPs (gluon coupling)		p, d	–
LHC-FT	charmed hadrons oEDMs	LHCb IP	7 TeV p	–
MeV-GeV mass range:				
SHiP	ALPs, Dark Photons, Dark Scalars	BDF, SPS	400 GeV p	$2\cdot 10^{20}$/5 years
	LDM, HNLs, lepto-phobic DM, ..			
NA62^{++}	ALPs, Dark Photons,	K12, SPS	400 GeV p	up to $3\cdot 10^{18}$/year
	Dark Scalars, HNLs			
NA64^{++}	ALPs, Dark Photons,	H4, SPS	100 GeV e^-	$5\cdot 10^{12}$ eot/year
	Dark Scalars, LDM			
	$+ L_\mu - L_\tau$	M2, SPS	160 GeV μ	$10^{12} - 10^{13}$ mot/year
	+ CP, CPT, leptophobic DM	H2-H8, T9	~ 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
AWAKE/NA64	Dark Photon	AWAKE beam	30-50 GeV e^-	10^{16} eot/year
RedTop	Dark Photon, Dark scalar, ALPs	CERN PS	1.8 or 3.5 GeV	10^{17} pot
MATHUSLA200	Weak-scale LLPs, Dark Scalar,	ATLAS or CMS IP	14 TeV p	3000 fb^{-1}
	Dark Photon, ALPs, HNLs			
FASER	Dark Photon, Dark Scalar, ALPs,	ATLAS IP	14 TeV p	3000 fb^{-1}
	HNLs, $B-L$ gauge bosons			
MilliQan	milli charge	CMS IP	14 TeV p	300-3000 fb^{-1}
CODEX-b	Dark Scalar, HNLs, ALPs,	LHCb IP	14 TeV p	300 fb^{-1}
	LDM, Higgs decays			
>> TeV mass range:				
KLEVER	$K_L \to \pi^0 \nu\bar{\nu}$	P42/K12	400 GeV p	$5\cdot 10^{19}$ pot /5 years
TauFV	LFV τ decays	BDF	400 GeV p	$o(2\%)$ of the BDF proton yield
CPEDM	p, d EDMs	EDM ring	p, d	–
	axions/ALPs (gluon coupling)		p, d	–
LHC-FT	charmed hadrons MDMs, EDMs	LHCb IP	7 TeV p	–

Non Accelerator-based

Accelerator-based

PBC-BSM Proposals in the North Area

NA62^{++} , KLEVER @ K12

400 GeV p beam

up to 3x10^{18} pot/year (now)

up to 10^{19} pot/year (upgrade)

NA64^{++}(e) @ H4

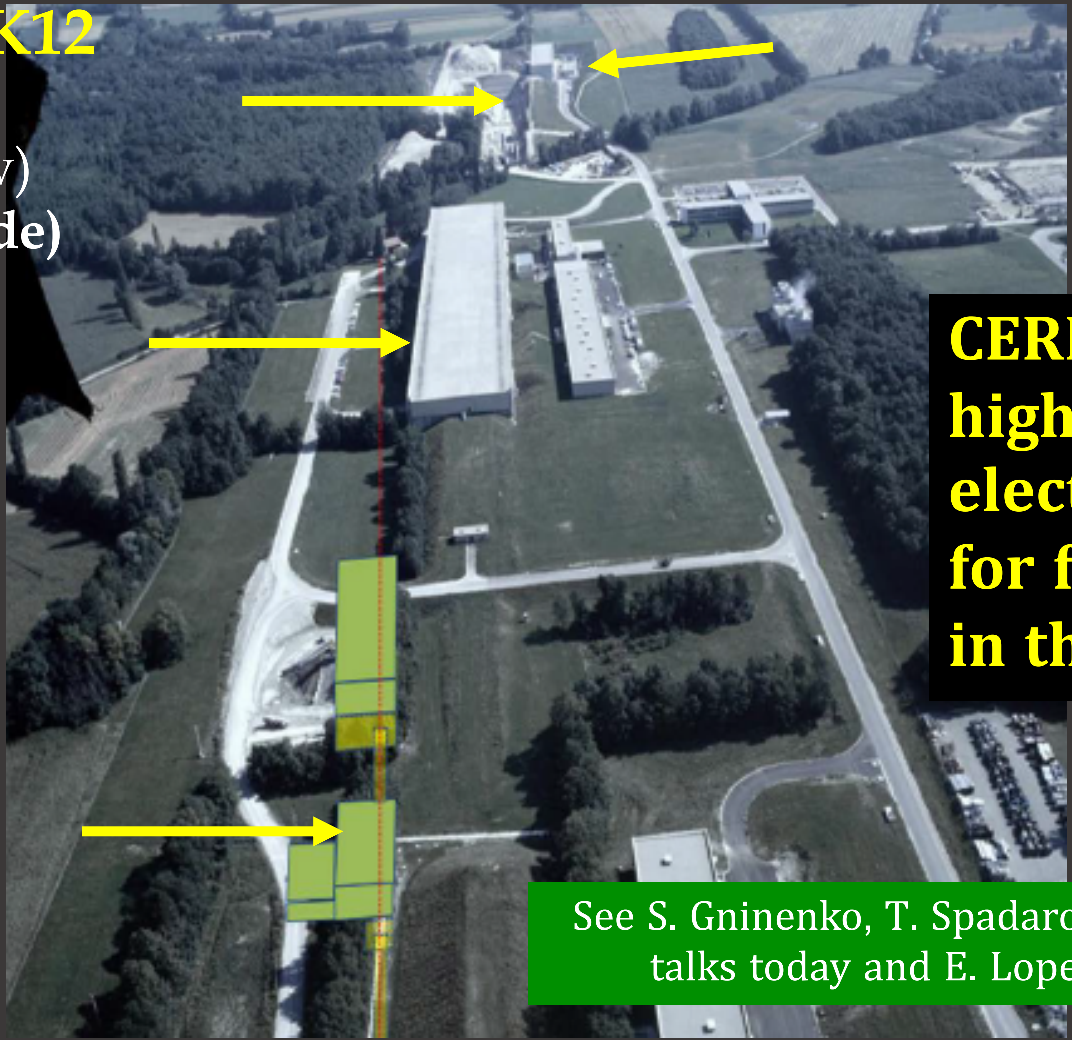
(100 GeV e- beam

up to 5x10^{12} eot/year)

SHiP, TauFV @ BDF

400 GeV p

up to 4x10^{19} pot/year



NA64^{++} (μ) @ M2

100-160 GeV muons,

up to 10^{13} μ/year

CERN can provide the highest energy proton, electron and muon beams for fixed target experiments in the world.

See S. Gninenko, T. Spadaro, E. Graverini, P. Collins , M. Moulson's talks today and E. Lopez Sola, J. Bernard's talks tomorrow

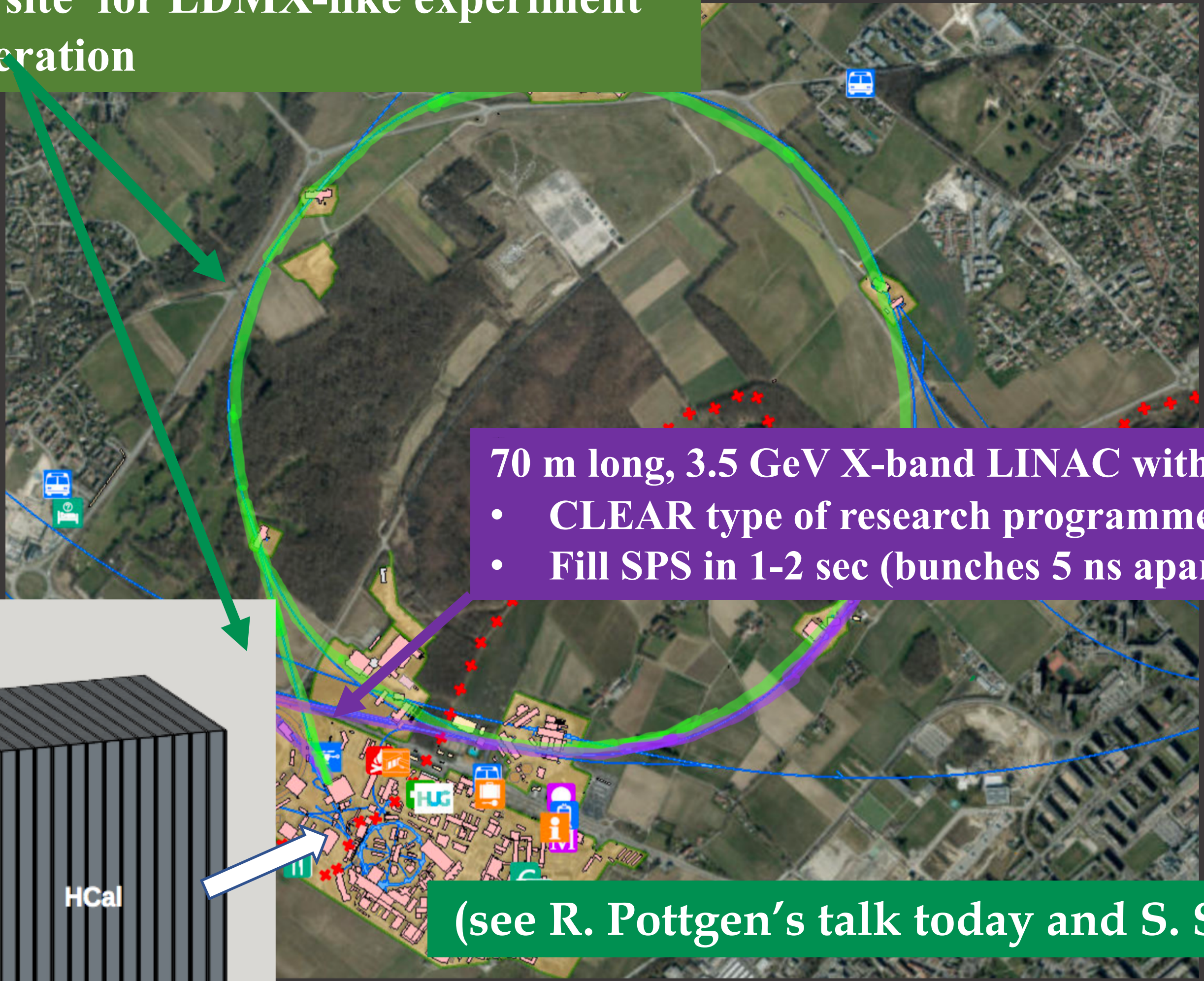
A possible "Hidden Sector Campus" (HSC)

LDMX @ eSPS: Meyrin area

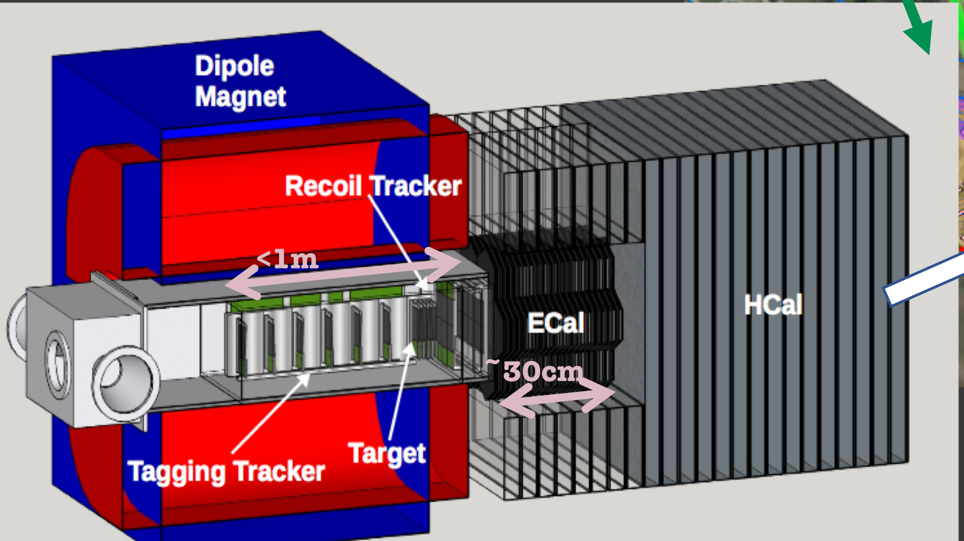
Missing momentum technique

GREEN: ~16 GeV electron beam in SPS
slow extraction towards Meyrin site for LDMX-like experiment
Up to 10^{16} eot in o(1) year of operation

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;**



(see R. Pottgen's talk today and S. Stapnes's talk tomorrow)

REDTOP @ CERN PS: Meyrin area

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:

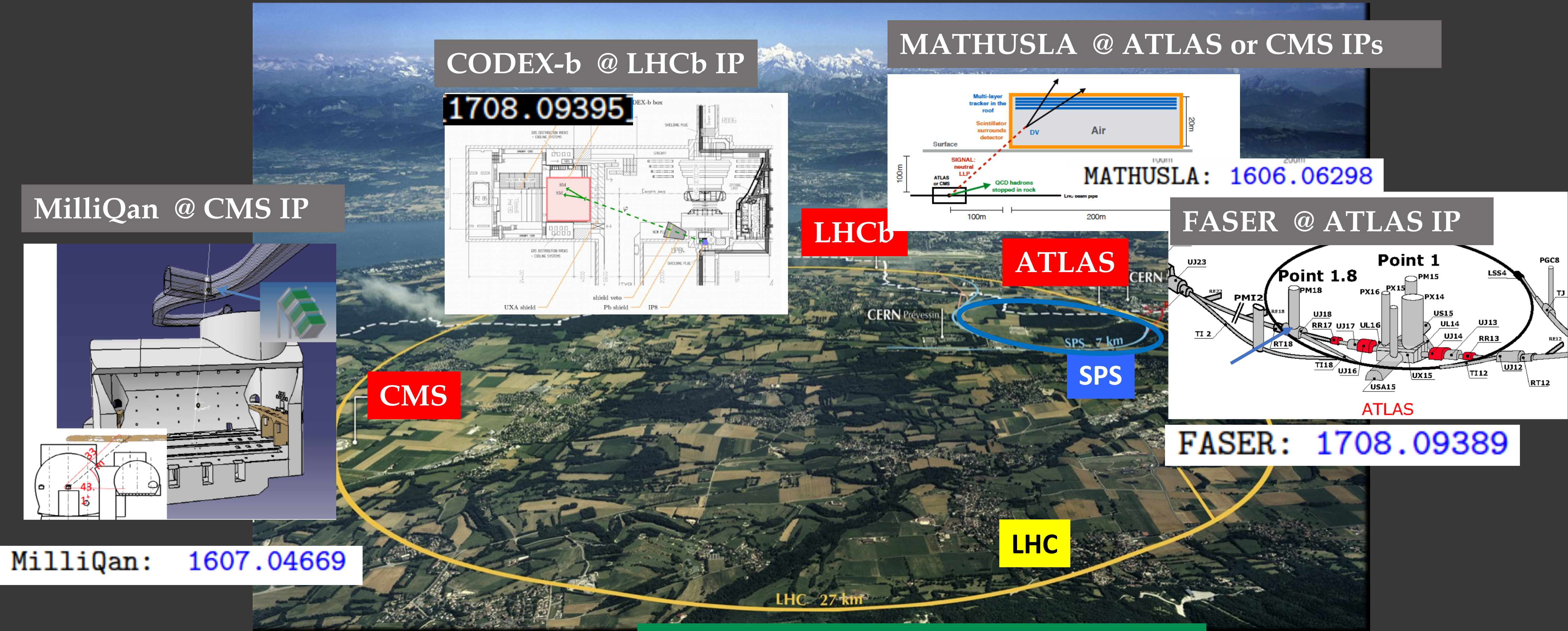
$$pLi \to \eta, \eta' \to A'\gamma \to \ell^+\ell^-\gamma \ (\ell = e, \mu)$$

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

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 within the Conventional Beams WG.

See R. Carosi's talk today and J. Bernhard's talk tomorrow morning

MilliQan, MATHUSLA, FASER, CODEX-b @ LHC IPs

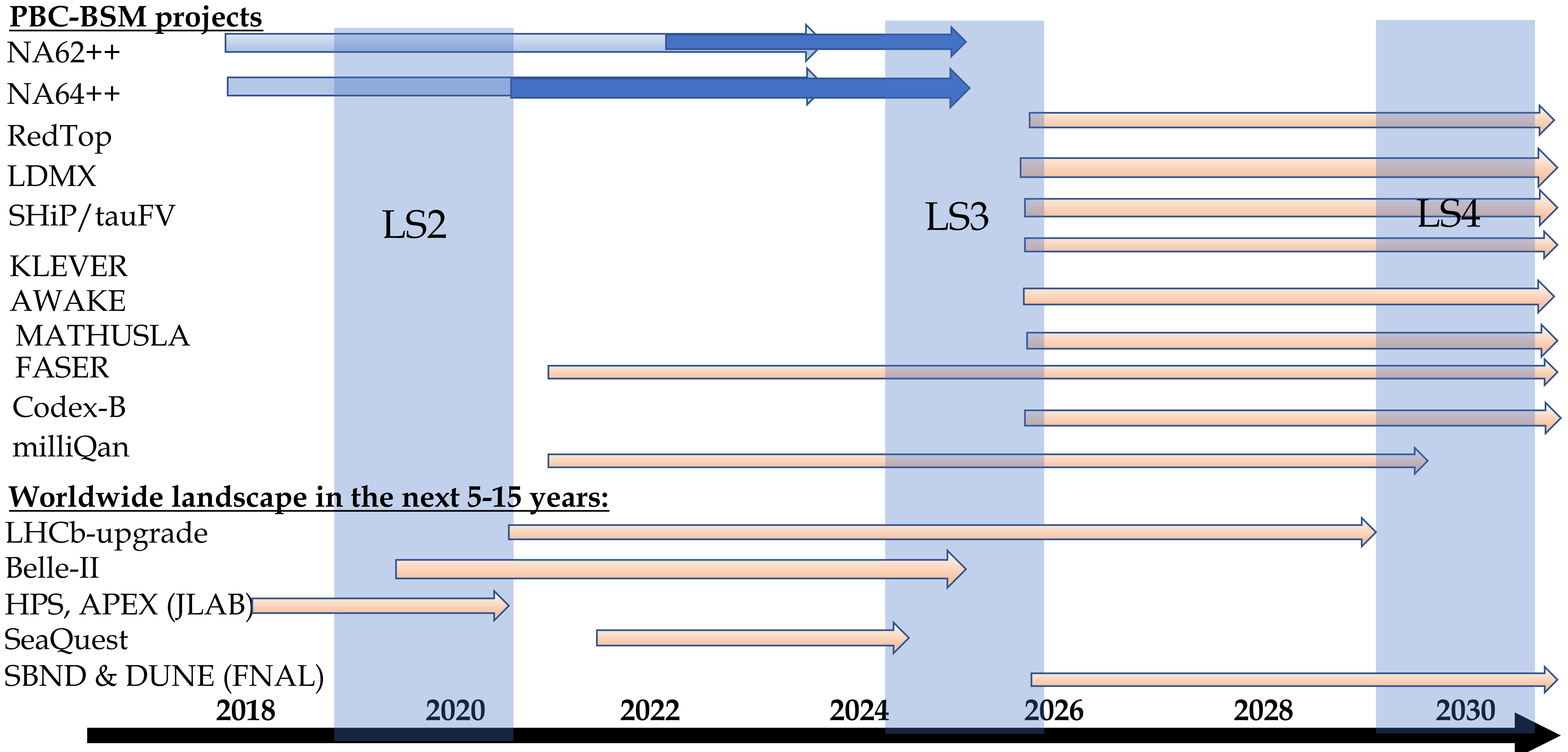


C. Alpigiani, B.Dey, F. Kling talks today

Beam Dump Technique

Timescale of accelerator-based PBC BSM projects

All PBC-BSM projects could be built and operated on 10-15 year timescale



Physics Reach of the PBC-BSM projects in a Worldwide Context

PBC-BSM: physics targets in the sub-eV and MeV-GeV ranges

HNLs, LDM & Light mediators, ALPs must be SM singlets, hence options limited by SM gauge invariance:
According to generic quantum field theory, the lowest dimension canonical operators are the most important:

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	$y_N L H N$

This is the set of the simplest fields and renormalizable interactions that can be added to the SM
to answer the three fundamental questions: DM nature, neutrino masses and oscillations, baryogenesis

The PBC BSM WG has identified 11 benchmark cases used to evaluate the experimental sensitivities
A common ground to compare the proposals against each other and put them in worldwide context

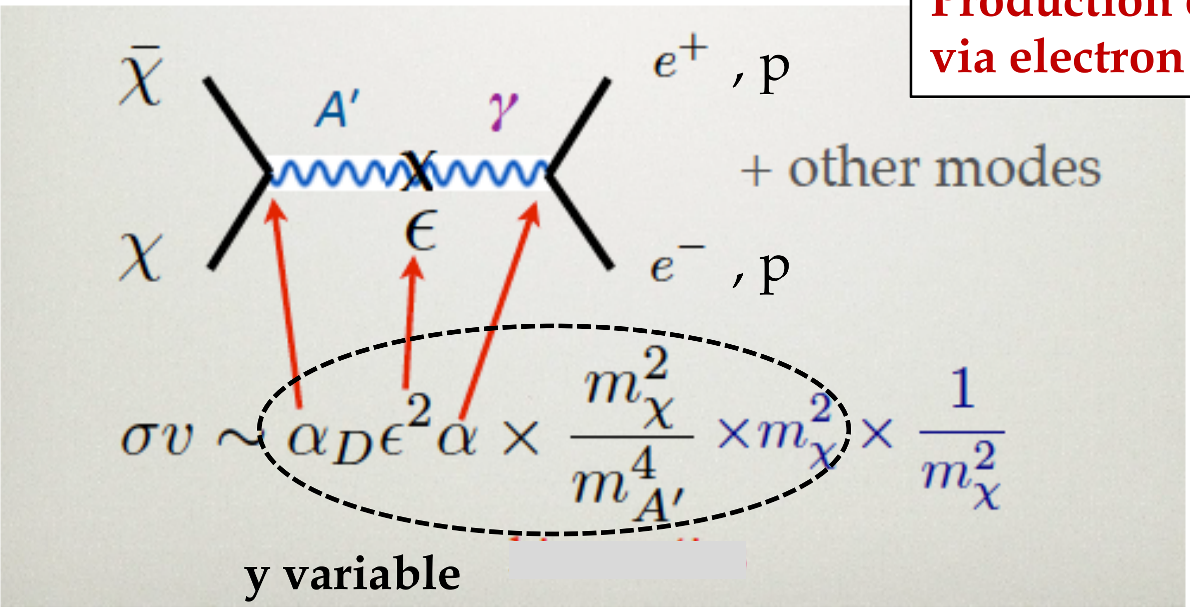
Dark Photon coupled to Light Dark Matter: connection with DM direct detection and cosmological bounds

Model where minimally coupled viable WIMP dark matter model can be constructed.
The parameter space for this model is $\{m_{A'}, \epsilon, m_\chi, \alpha_D\}$

$$A' \rightarrow \chi\chi$$

Production of DM at accelerators via electron or proton bremsstrahlung

Direct DM scattering with e/protons: Direct Detection experiments



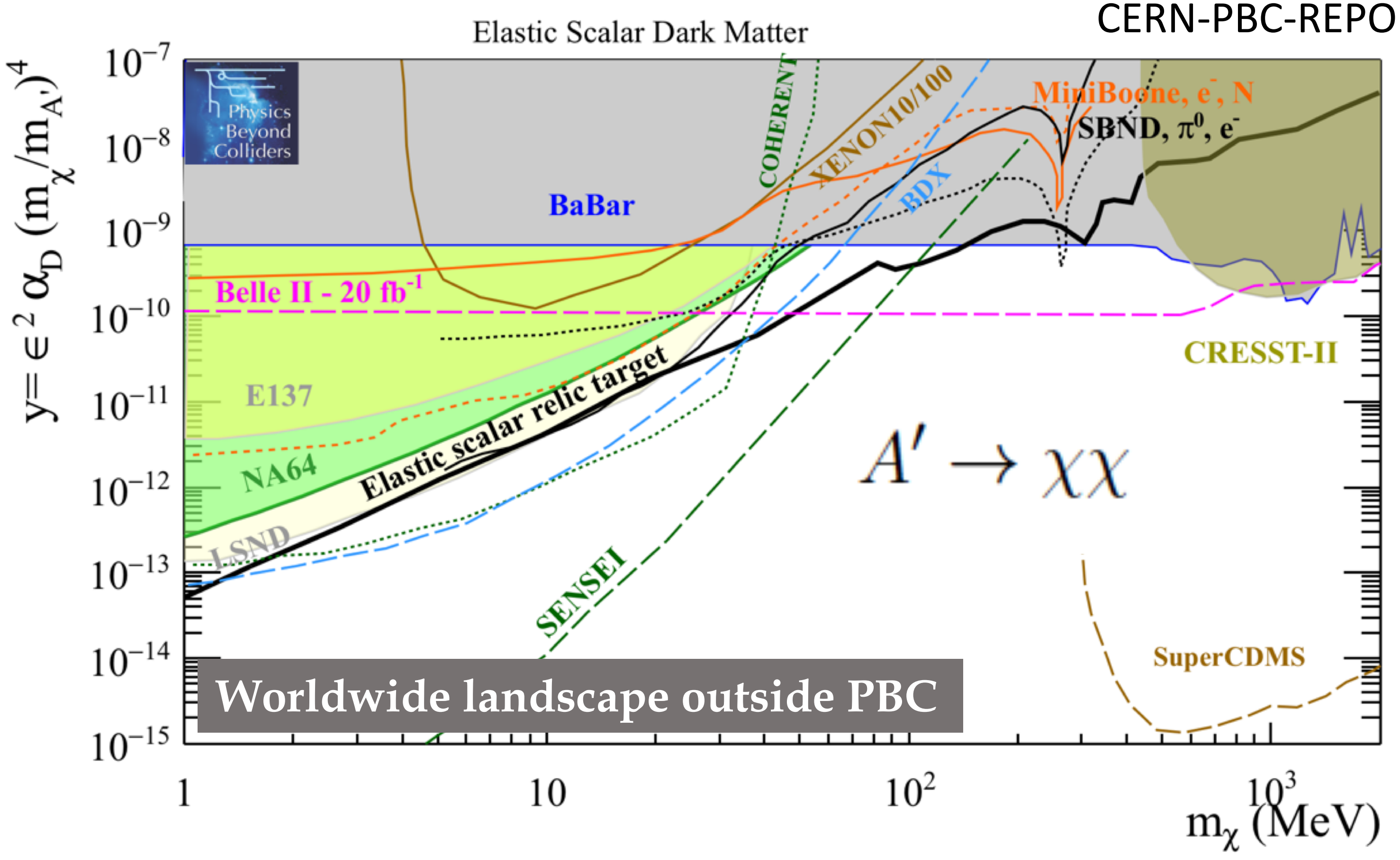
Courtesy of P. Schuster

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

Dark Photon coupled to Light Dark Matter (Benchmark #2)

Model where minimally coupled viable WIMP dark matter model can be constructed.
The parameter space for this model is: $\{m_{A'}, \epsilon, m_\chi, \alpha_D\}$

CERN-PBC-REPORT-2018-007



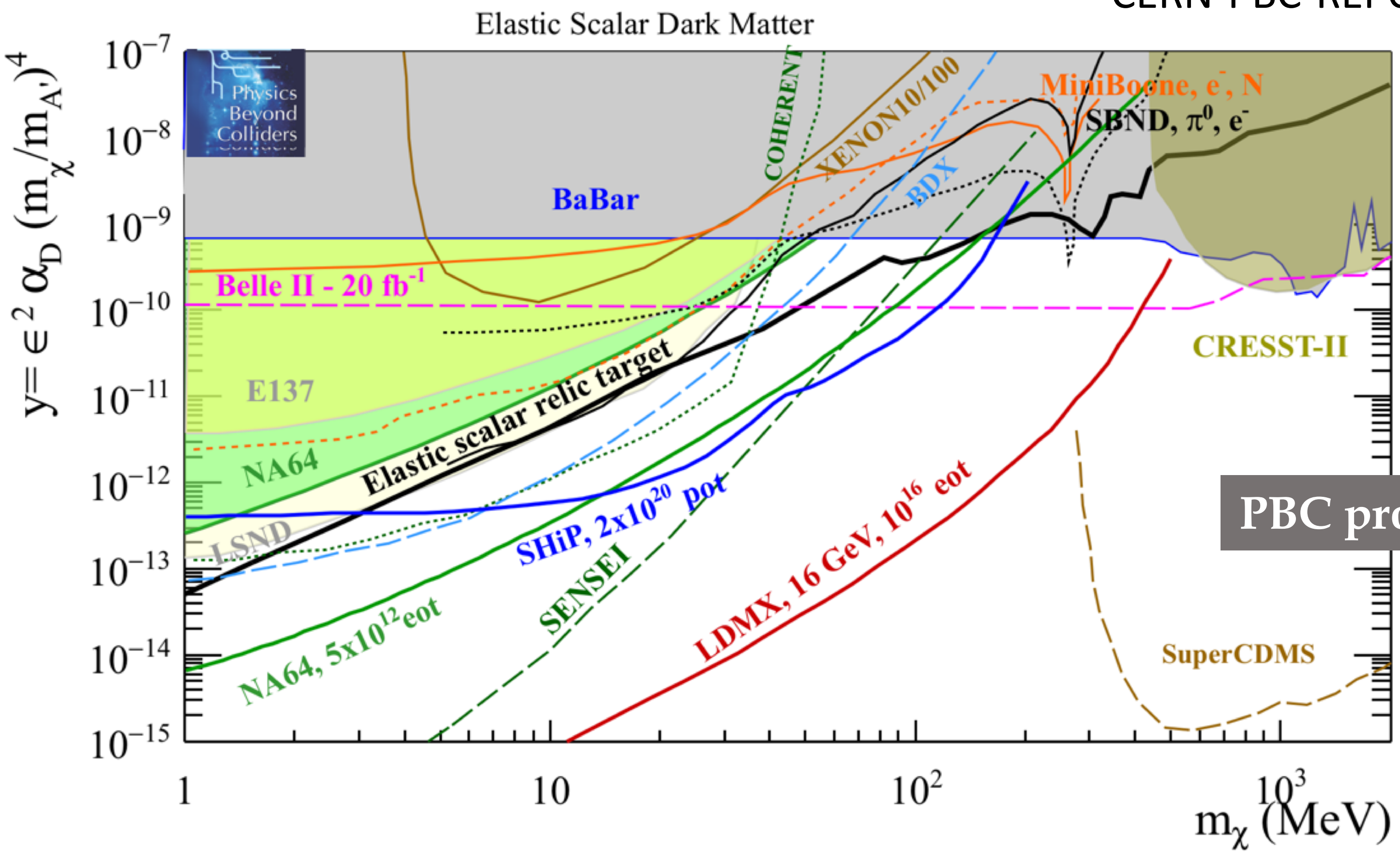
$m(A') = 3\, m(\chi)$
$\alpha(D) = 0.1$

Nice complementarity
between accelerator-based proposals and Light DM direct detection experiments.

Dark Photon coupled to Light Dark Matter (Benchmark #2)

Model where minimally coupled viable WIMP dark matter model can be constructed.
The parameter space for this model is: $\{m_{A'}, \epsilon, m_\chi, \alpha_D\}$

CERN-PBC-REPORT-2018-007



$$A' \rightarrow \chi\chi$$

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

PBC projects: 5-15 years outlook

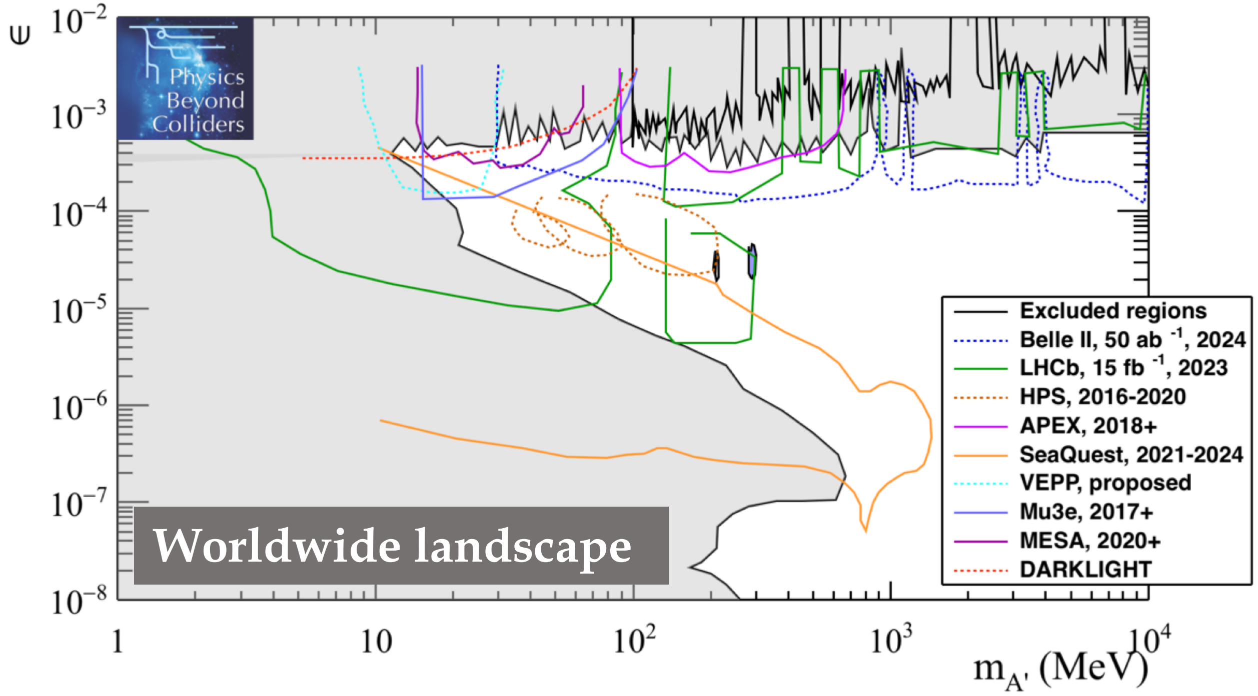
Nice complementarity
between accelerator-based proposals and Light DM direct detection experiments.

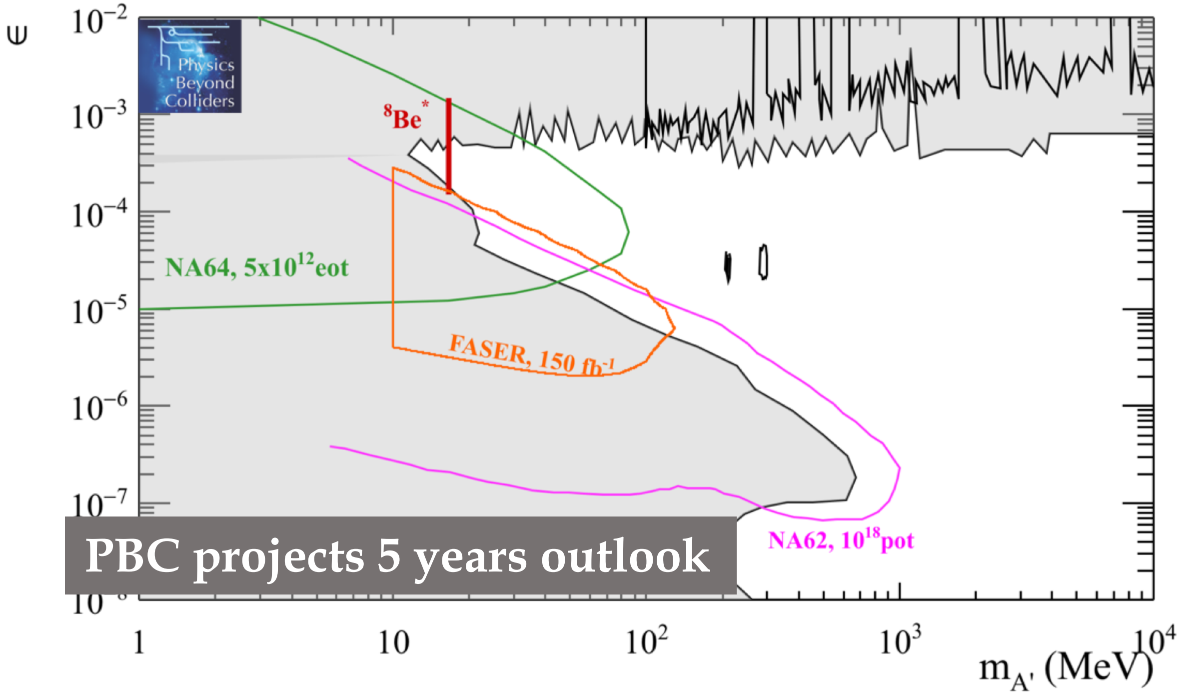
Dark Photon coupled to SM particles (Benchmark #1)

The SM is augmented by a single new state A'. DM is assumed to be either heavy or contained in a different sector.

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

CERN-PBC-REPORT-2018-007





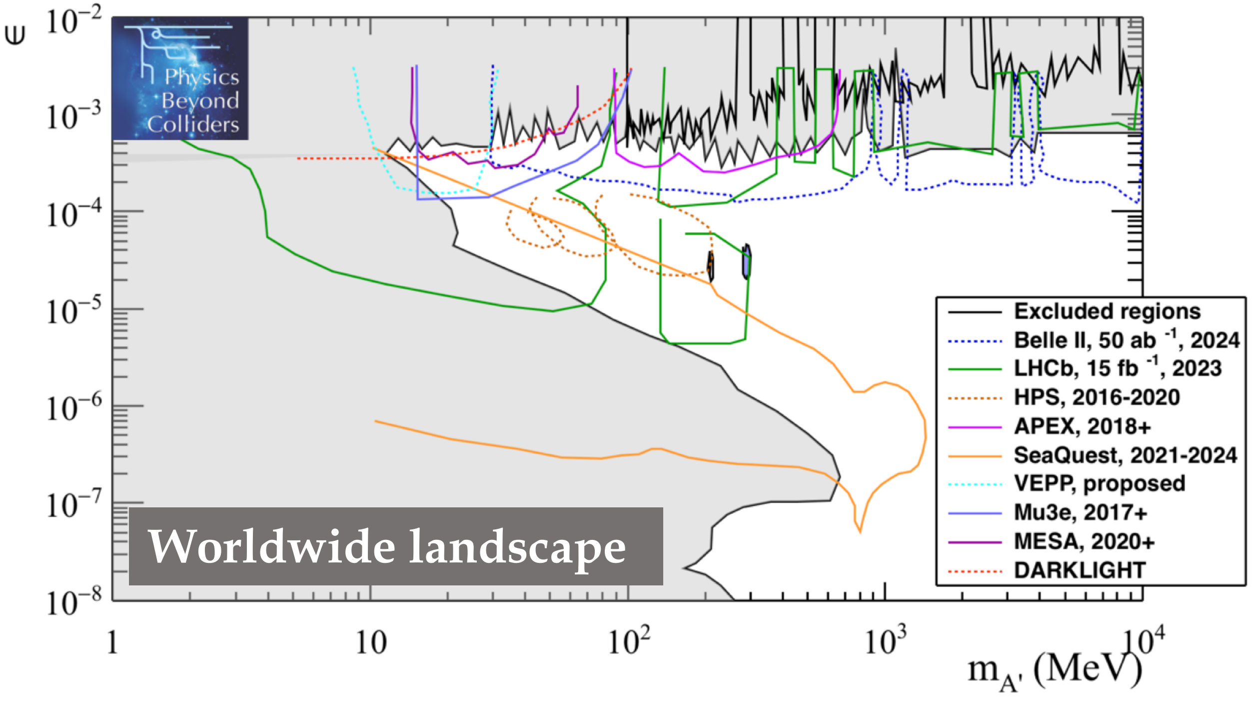
Nice complementarity/competition
with experiments in Japan, FNAL, JLAB, Mainz, PSI…..

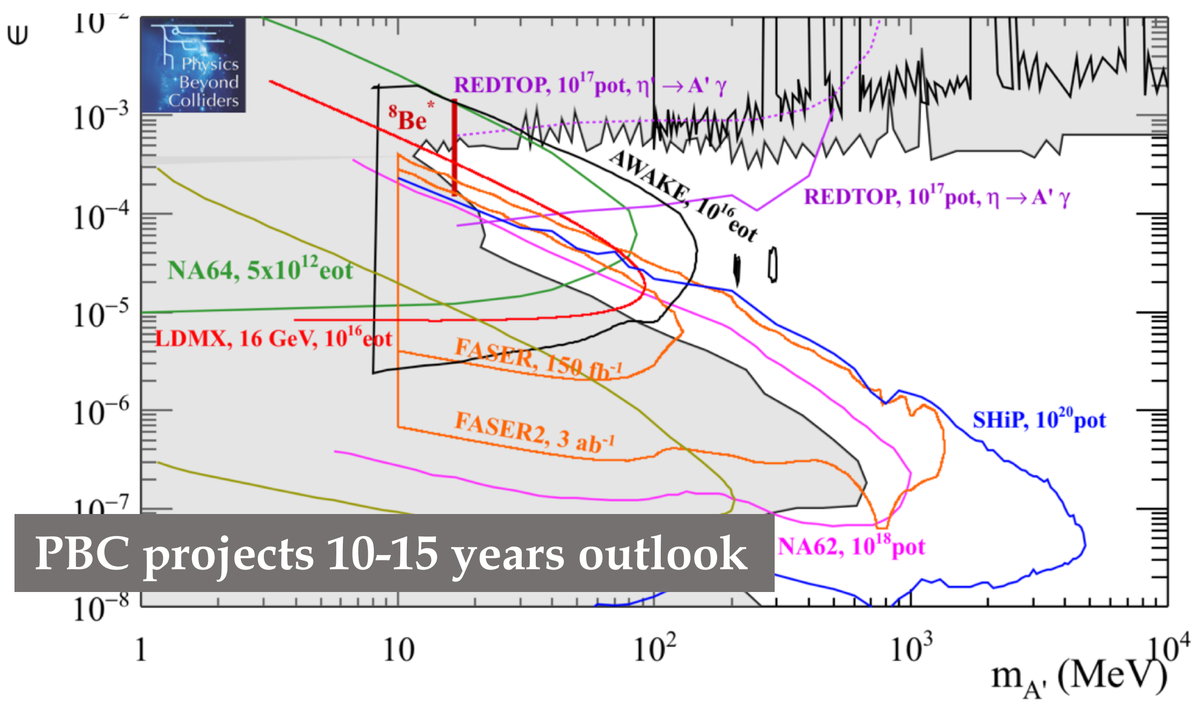
Dark Photon coupled to SM particles (Benchmark #1)

The SM is augmented by a single new state A'. DM is assumed to be either heavy or contained in a different sector.

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

CERN-PBC-REPORT-2018-007





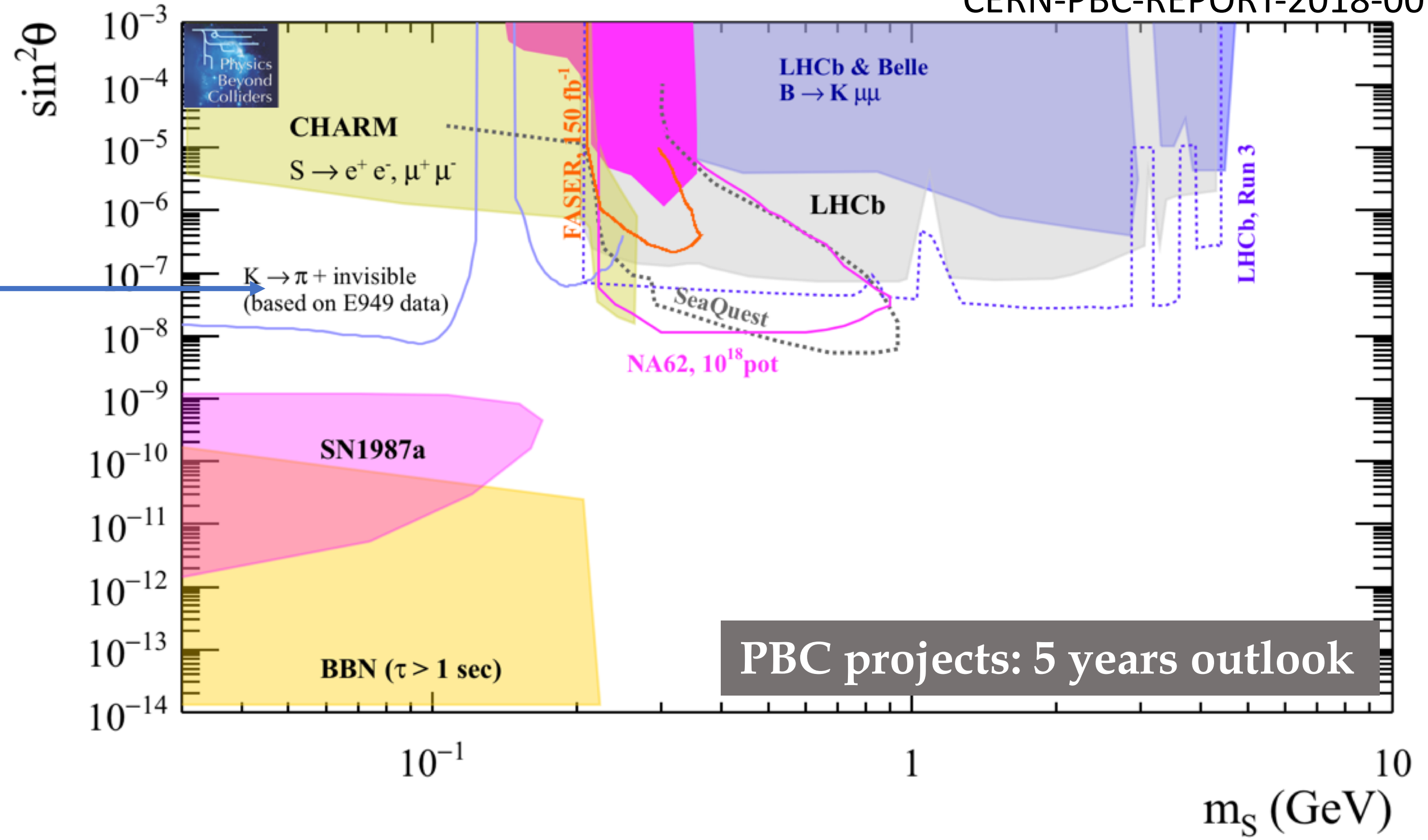
Nice complementarity/competition
with experiments in Japan, FNAL, JLAB, Mainz, PSI…..

Dark Scalar coupled to the Higgs (Benchmarks #4-5)

The Higgs portal 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**.
Benchmark 4: assume **λ**=0.

CERN-PBC-REPORT-2018-007

Relaxion DM?

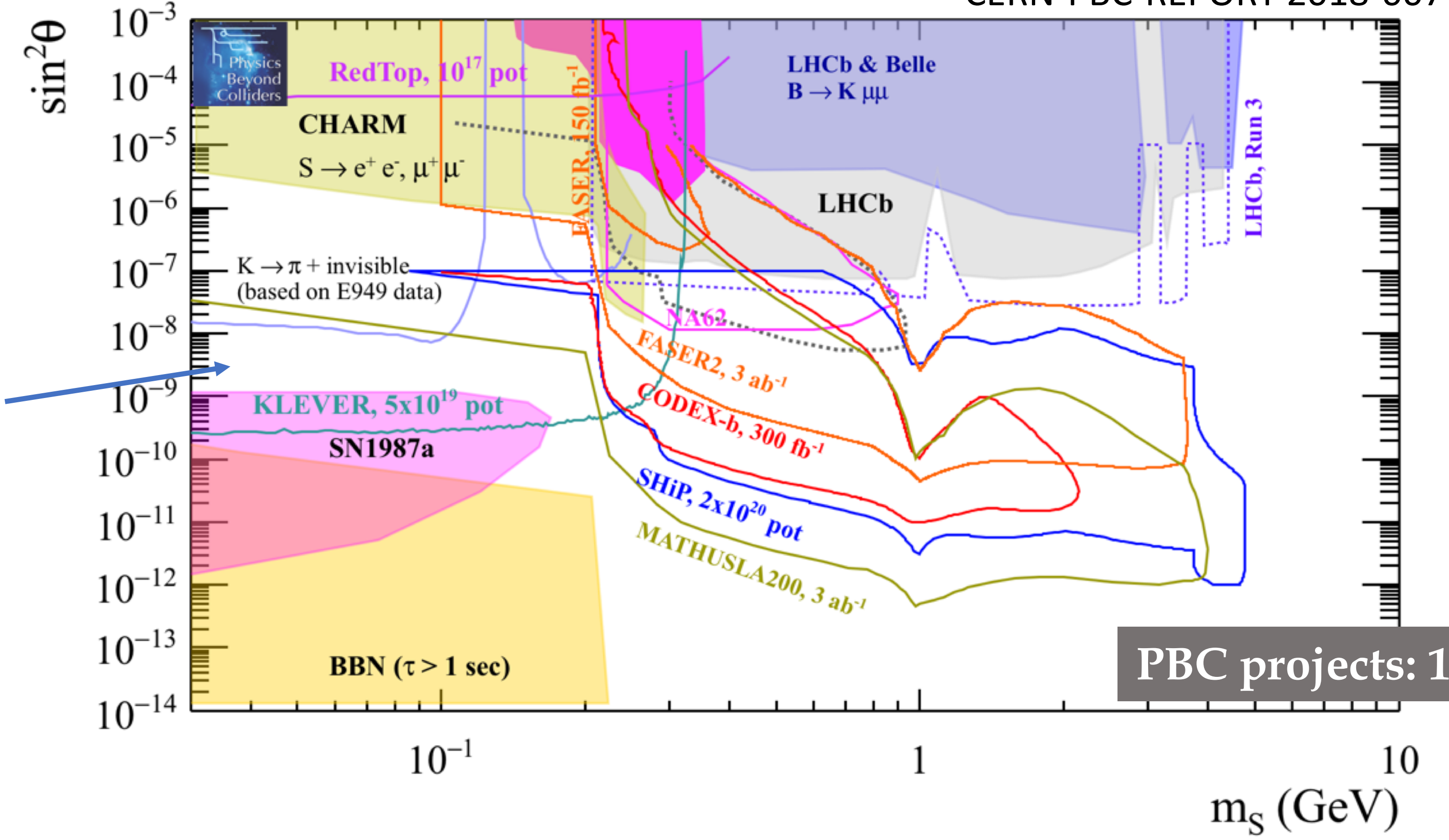


Nice complementarity with colliders and astrophysical data

Dark Scalar coupled to the Higgs (Benchmarks #4-5)

The Higgs portal 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**.
Benchmark 4: assume **λ**=0.

CERN-PBC-REPORT-2018-007



Relaxion DM?

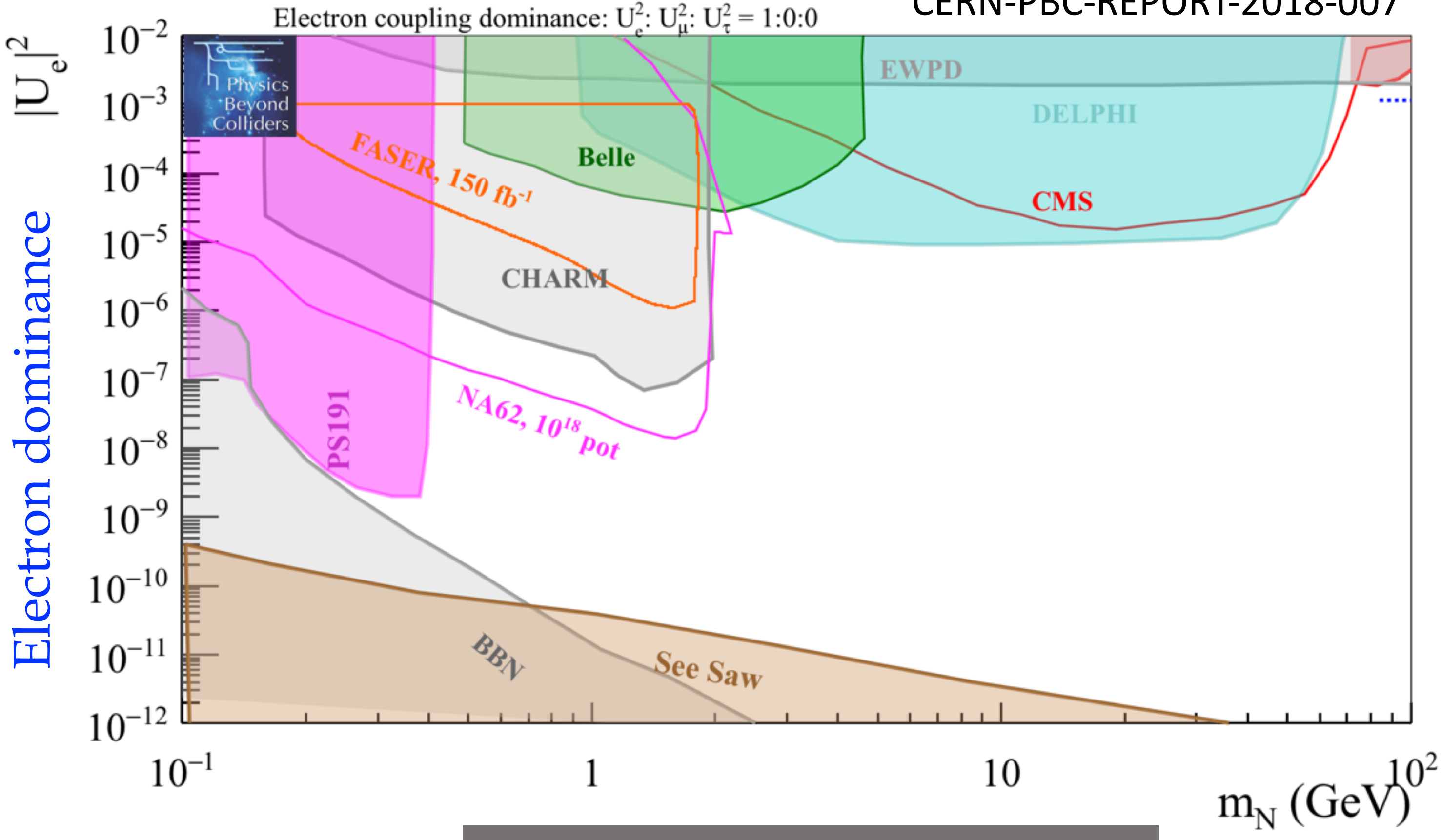
PBC projects: 10-15 year outlook

Nice complementarity with astrophysical data

HNLs below the EW scale (benchmarks #6,7,8):

Neutrino portal extension of the SM is very motivated by the fact that it can be tightly related with the neutrino mass generation mechanism: Heany Neutral Leptons or HNLs.
Choice of the PBC is to assume the single-flavor dominance, eg. HNLs couple only with one flavor of the active neutrinos at the time.

CERN-PBC-REPORT-2018-007

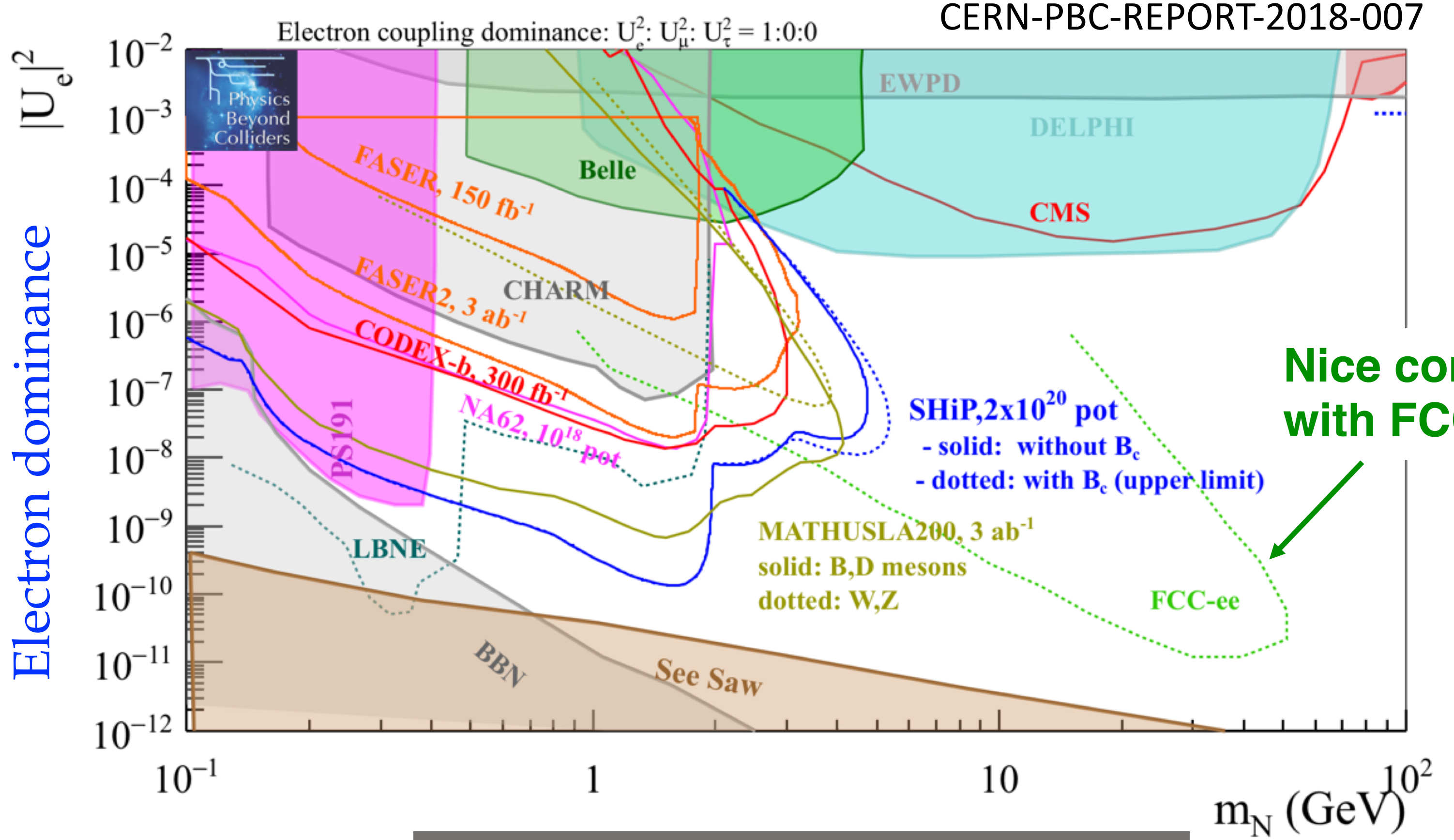


PBC projects: ~5 year outlook

Benchmarks 6,7,8: HNLs below the EW scale:

Neutrino portal extension of the SM is very motivated by the fact that it can be tightly related with the neutrino mass generation mechanism: Heany Neutral Leptons or HNLs.
Choice of the PBC is to assume the single-flavor dominance, eg. HNLs couple only with one flavor of the active neutrinos at the time.

CERN-PBC-REPORT-2018-007

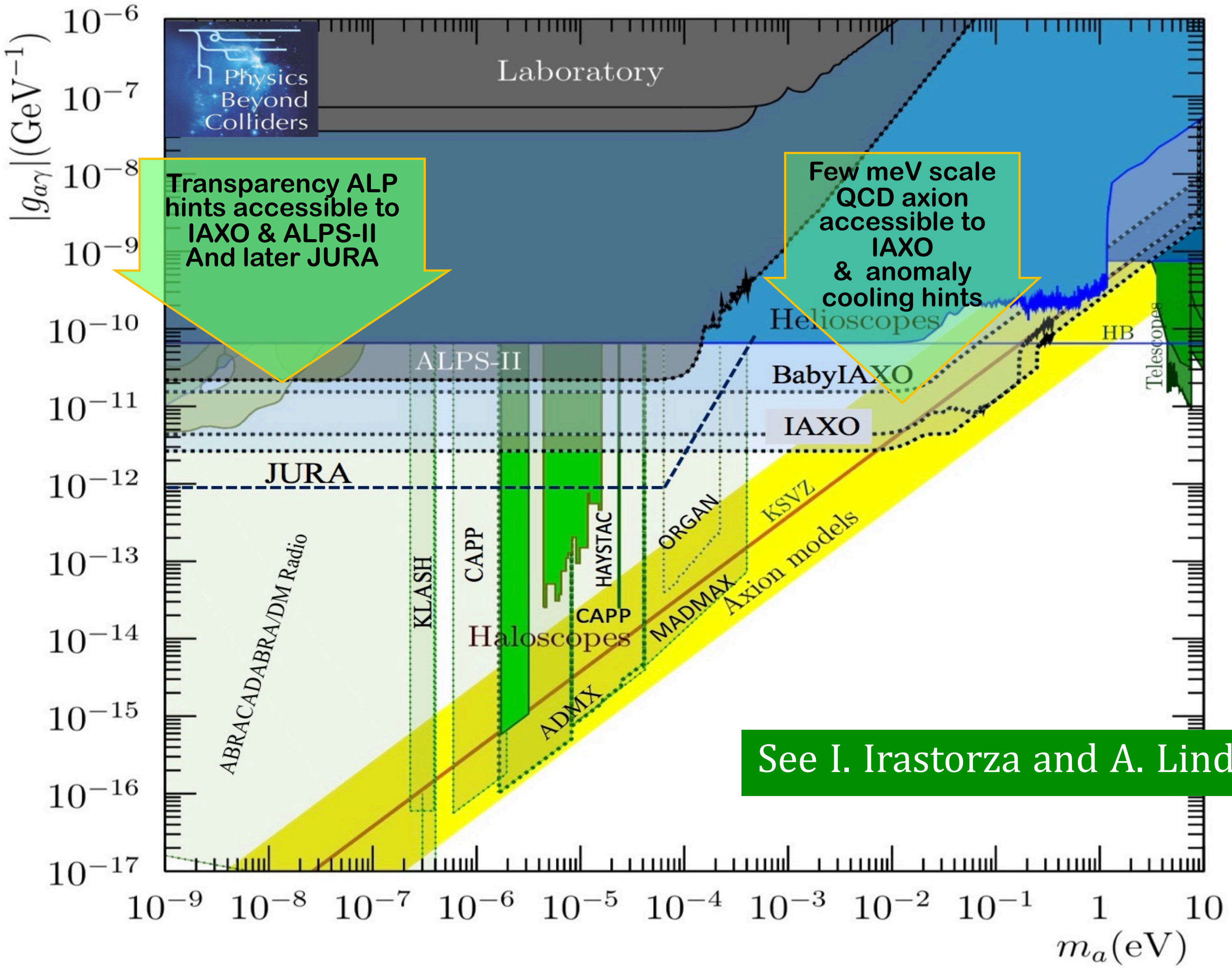


Nice complementarity with FCC-ee

PBC projects: ~10-15 year outlook

Axions and ALPS with photon coupling in the sub-eV mass range: PBC-BSM projects: baby-IAXO, IAXO and Jura

(see I. Irastorza's & A. Linder's talks today)



IAXO and JURA mostly considered in the Technology WG for support in:

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

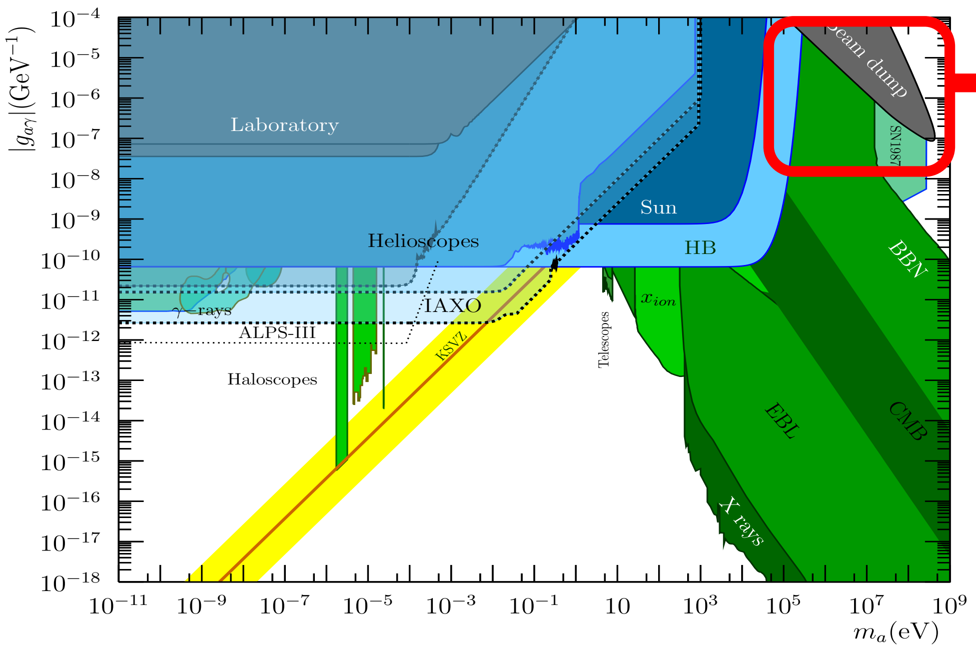
See I. Irastorza and A. Lindner's talk today

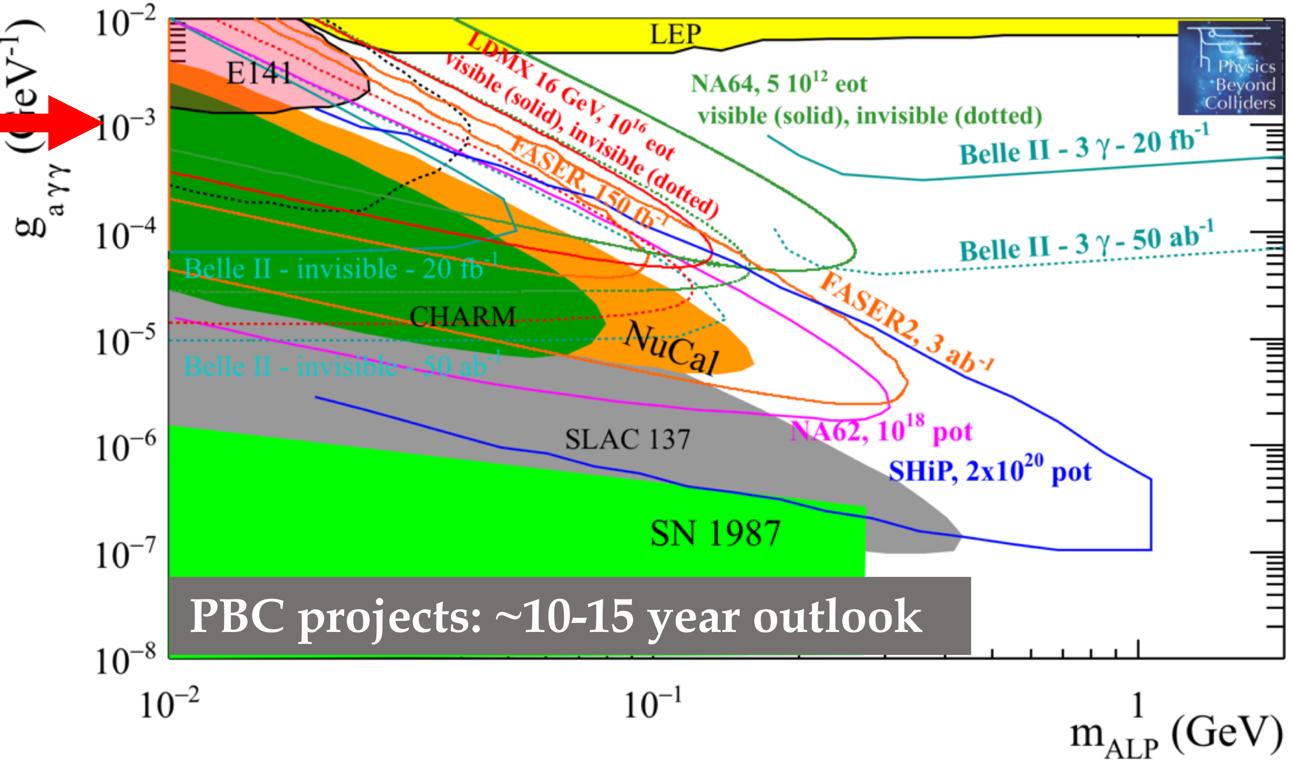
Axions and ALPS with photon coupling in the MeV-GeV mass range

Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range
Need of a systematic investigation in the MeV-GeV range.

zoom in the MeV-GeV range

axion. $ALP \to \gamma\gamma$





Similar sensitivity plots for ALPs with fermion and gluon couplings in the PBC-BSM document

Nice complementarity of accelerator-based experiment
with experiments in the sub-eV range and cosmological bounds

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

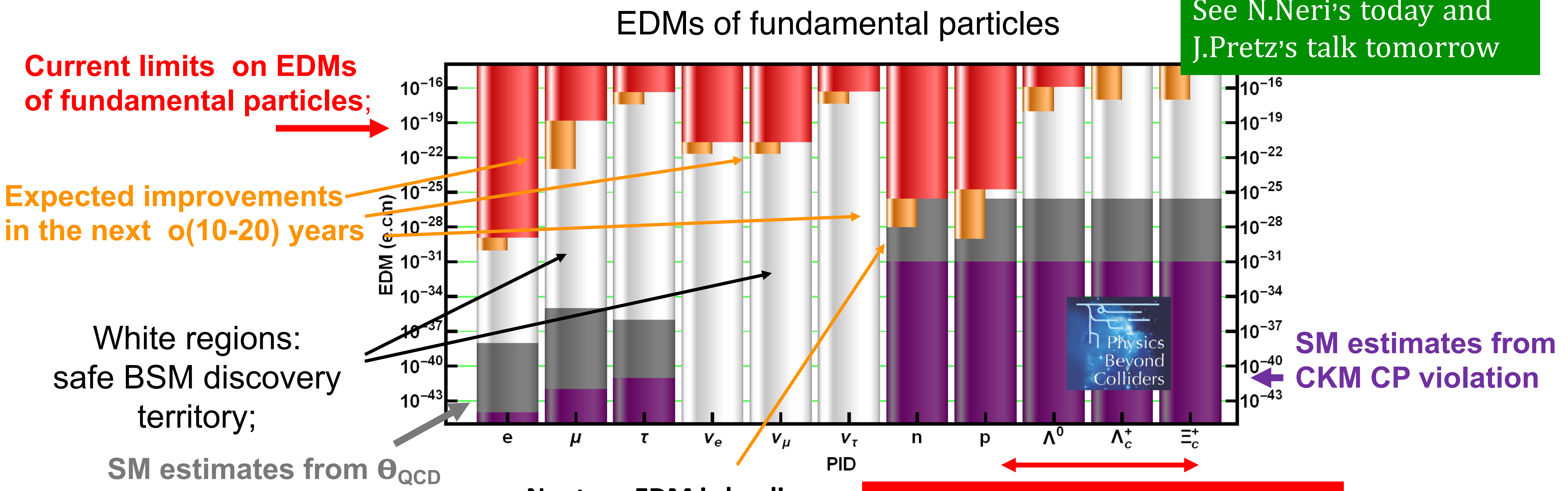
Proposal	Background	Efficiency	Based on
at the PS:			
RedTop	included	included	full simulation
at the SPS:			
KLEVER	$K_L \to \pi^0\nu\overline{\nu}, K_L \to \pi^0\pi^0$ bkgs included	included	Main backgrounds and efficiencies evaluated with fast simulation and partly validated with the full (NA62-based) Monte Carlo
LDMX	background included	included	full Geant4 simulation for 4 GeV beam
NA62^{++}	zero background proven for fully reconstructed final states	partially included	analysis of $\sim 3 \cdot 10^{16}$ 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	–
AWAKE/NA64	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 $\sim 10^{12}$ pot measurement of the muon flux at H4 performed in July 2018
at the LHC:			
CODEX-b	zero background assumed (preliminary GEANT simulation)	not included	Evaluation of background in progress with full MC
FASER	zero background assumed	not included	Fluka simulation and in-situ measurements
MATHUSLA200	zero background assumed	not included	FLUKA, Pythia and MadGraph simulation for $\nu-$, $\mu-$ fluxes from the LHC IP and cosmic rays background.
MilliQan	included	included	full Geant4 simulation of the detector

Just a starting point of a long way.

Axions and ALPS with gluon coupling as probes of the multi-TeV range

Study of the permanent EDMs in proton/deuteron and in charmed and strange baryons with the CP-EDM and LHC-FT proposals as probe of multi-TeV NP scale.

See N.Neri's today and J.Pretz's talk tomorrow



PBC targets
(CP-EDM and LHC-FT proposals)

Physics Beyond Colliders

Search for NP at the multi-TeV scale: the KLEVER Project

CERN

KLEVER target:
measure ~ 60 SM $K_L \rightarrow \pi^0 \nu\nu$ with S/B ~ 1, hence precision of 20% on the BR with 5 years running starting in Run 4. This requires x6 increase beam intensity wrt NA62.

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.

New Physics can affect differently K^+ and K_L channels

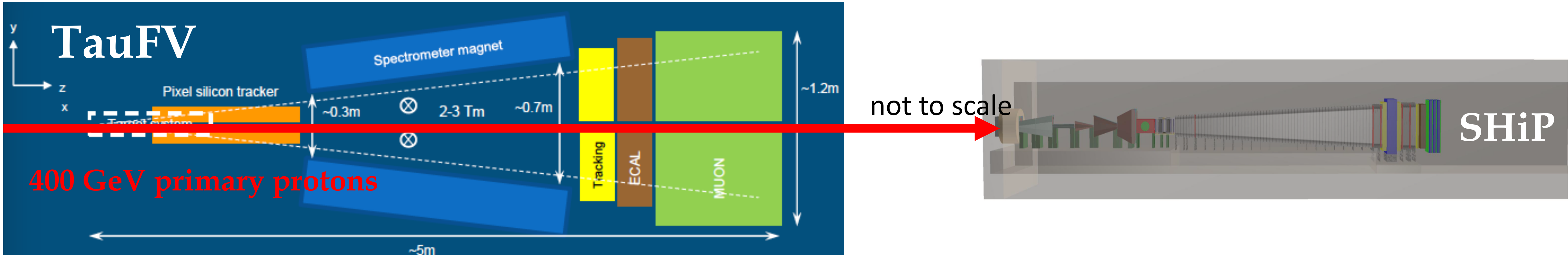
CERN-PBC-REPORT-2018-007

Model	Λ [TeV]	Effect on BR($K^+ \to \pi^+ \nu\bar{\nu}$)	Effect on BR($K_L \to \pi^0 \nu\bar{\nu}$)	Refs.
Leptoquarks, most models	1–20	Very large enhancements; mainly ruled out		[338]
Leptoquarks, U_1	1–20	+10% to +60%	+100% to +800%	[338]
Vector-like quarks	1–10	−90% to +60%	−100% to +30%	[339]
Vector-like quarks + Z'	10	−80% to +400%	−100% to 0%	[339]
Simplified modified Z, no tuning	1	−100% to +80%	−100% to −50%	[340]
General modified Z, cancellation to 20%	1	−100% to +400%	−100% to +500%	[340]
SUSY, chargino Z penguin	4–6 TeV		−100% to −40%	[341]
SUSY, gluino Z penguin	3–5.5 TeV	0% to +60%	−20% to +60%	[342]
SUSY, gluino Z penguin	10	Small effect	0% to +300%	[343]
SUSY, gluino box, tuning to 10%	1.5–3	±10%	±20%	[344]
LHT	1	±20%	−10% to −100%	[345]

(See M. Moulson's talk today and J. Bernhard's talk tomorrow)

Search for NP at the multi-TeV scale: the TauFV Project

- ✓ Long-standing, and well motivated (particularly since the discovery of neutrino oscillations) program of searches for charged Lepton Flavour Violation.
- ✓ Study of tau LFV decays very timely: complement the quest for new physics in other cLFV modes, as mu2e @ FNAL and MEG/mu3e @ PSI.
- ✓ 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.



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

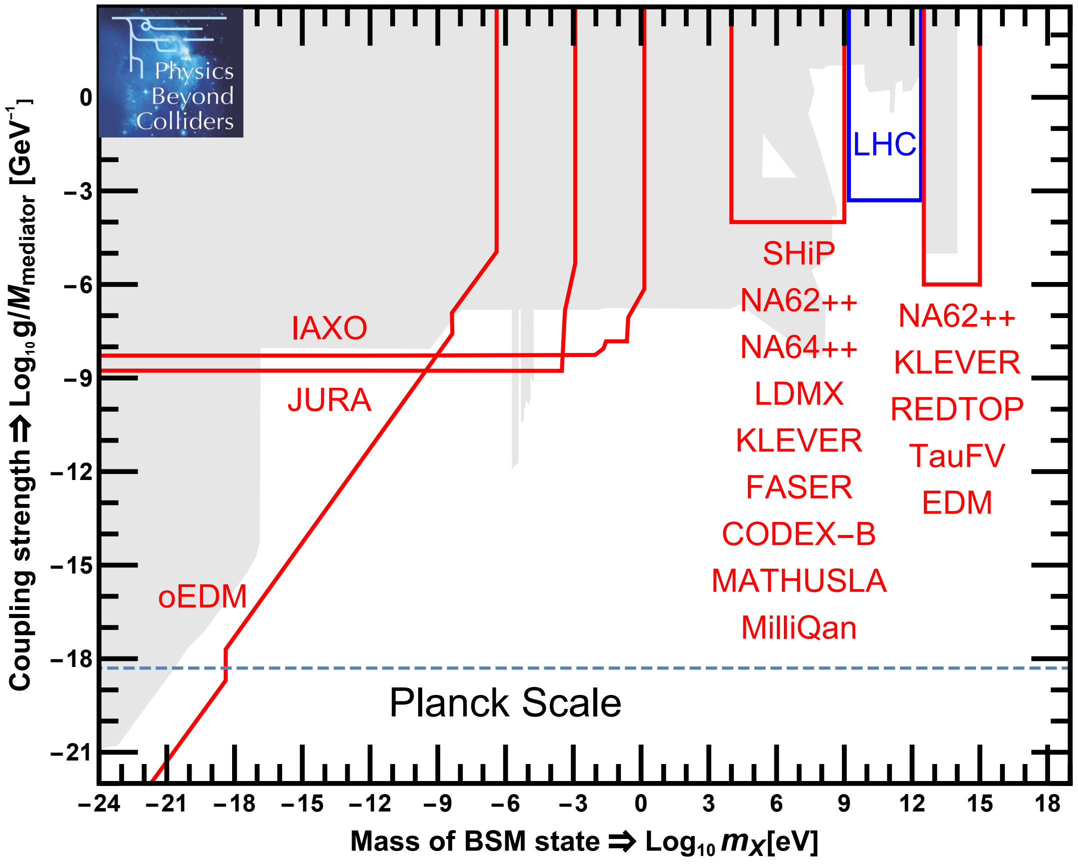
Eg: $\tau \longrightarrow \mu\mu\mu$ yield assuming a BR ~ 10^{-9}

Future experiment	Yield	Extrapolated from
TauFV (4×10^{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

See P.Collins's talk today

PBC-BSM target: Axion and Axion-Like Particles

Schematic Physics Reach of PBC projects for axion/ALPs coupled to photons and gluons, compared to the LHC.



Large complementarity with the LHC, HL-LHC and future colliders programme.

PBC-BSM Working Group deliverables

- ✓ **PBC-BSM work summarized in a ~140 pp long report:**
  CERN-PBC-REPORT-2018-007
  will be submitted to arXiv next week.
  as a support document of the main PBC document submitted to the ESPP update.

- ✓ **Individual contributions submitted to the ESPP update:**
  - REDTOP, IAXO, NA64++, KLEVER, SHiP, LDMX, TauFV, FASER, MATHUSLA.
  - IAXO and JURA also part of the document:
  "A European Strategy Towards Finding Axions and Other WISPs

- ✓ **Food for thought for the ESPP Physics Preparatory Group….**

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PBC-REPORT-2018-007
18 December 2018

Report of the BSM Working Group of the Physics Beyond Colliders at CERN

J. Beacham[1], C. Burrage[2,•], D. Curtin[3], A. De Roeck[4], J. Evans[5], J. L. Feng[6], C. Gatto[7], S. Gninenko[8], A. Hartin[9], I. Irastorza[10], J. Jaeckel[11], K. Jungmann[12,•], K. Kirch[13,•], F. Kling[6], S. Knapen[14], M. Lamont[4], G. Lanfranchi[15,•], C. Lazzeroni[16], A. Lindner[17], F. Martinez-Vidal[18], M. Moulson[15], M. Papucci[4,19], I. Pedraza[20], K. Petridis[21], M. Pospelov[22,•], A. Rozanov[23,•], G. Ruoso[24,•], P. Schuster[25], Y. Semertzidis[26], T. Spadaro[15], C. Vallée[23], and G. Wilkinson[27].

Abstract

The Physics Beyond Colliders initiative is an exploratory study aimed at exploiting the full scientific potential of the CERN's accelerator complex and scientific infrastructures through projects complementary to the LHC and other possible future colliders. These projects will target fundamental physics questions in modern particle physics. This document presents the status of the proposals presented in the framework of the Beyond Standard Model physics working group, and explore their physics reach and the impact that CERN could have in the next 10-20 years on the international landscape.

Conclusions

- The target of the PBC-BSM activity is a broad, rich and compelling physics programme which addresses the open questions of particle physics in a complementary way to the LHC, HL-LHC, FCC and other initiatives in the world (e.g. DM direct detection, astrophysical data, experiments at JLAB, FNAL).

- This program aims at exploiting the unique CERN scientific infrastructure and accelerator complex on a 5-15 year timescale.

- 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.

- The experimental collaborations are backed by a very active theory community and the PBC has served as fertile ground where models have been developed, discussed, and improved.

- A preliminary set of comparative plots, based on theoretically and phenomenologically motivated models, shows the scientific potential and the impact that CERN could have on the international landscape in the next o(10-15) years in the quest for New Physics .

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

A warm thank you to the PBC main conveners (Claude, Joerg, Mike) and all the BSM WG members for the hard but very interesting work we have done together.

SPARES

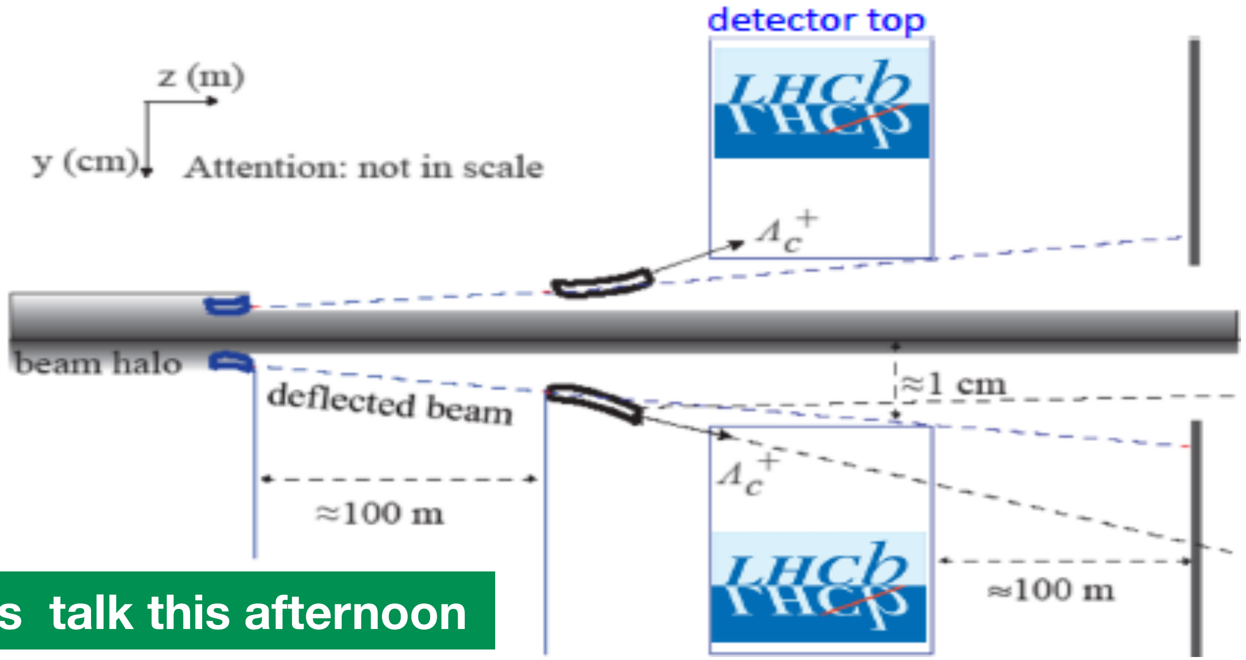
LHC-FT: EDMs in charmed hadrons

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 does not respect chiral symmetry then

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

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

- If perturbative: x~ 10^{-2} , down to (10^{-19} -10^{-20}) e cm level and below.
- If respecting chiral dynamics: x yc ~ 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 this afternoon

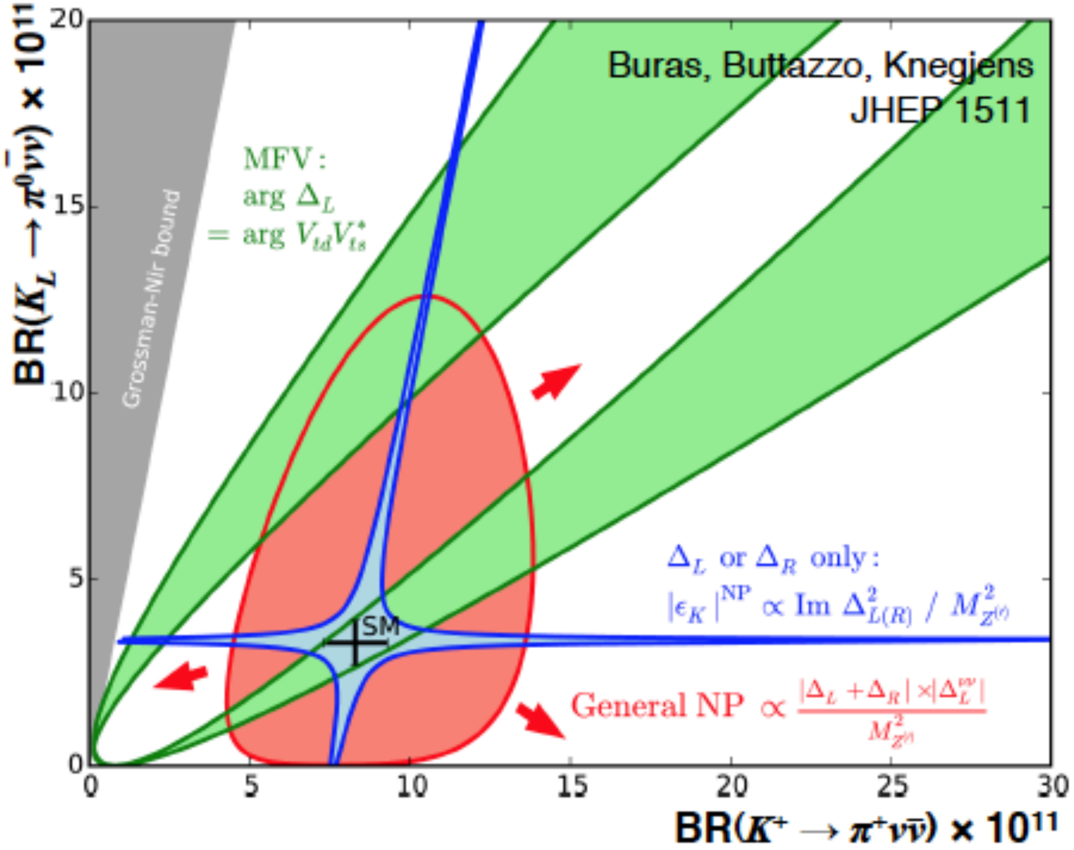
KLEVER @ K12: an experiment to measure $K_L \to \pi^0 \nu \nu$ branching fraction

Current status: BR($K_L \to \pi^0 \nu \nu$) (SM) = $(3.4 \pm 0.6)\ 10^{-11}$

BR($K_L \to \pi^0 \nu \nu$) (E391a) < 2.6 10^{-8} (90% CL)

New physics affects BRs differently for K^+ and K_L channels

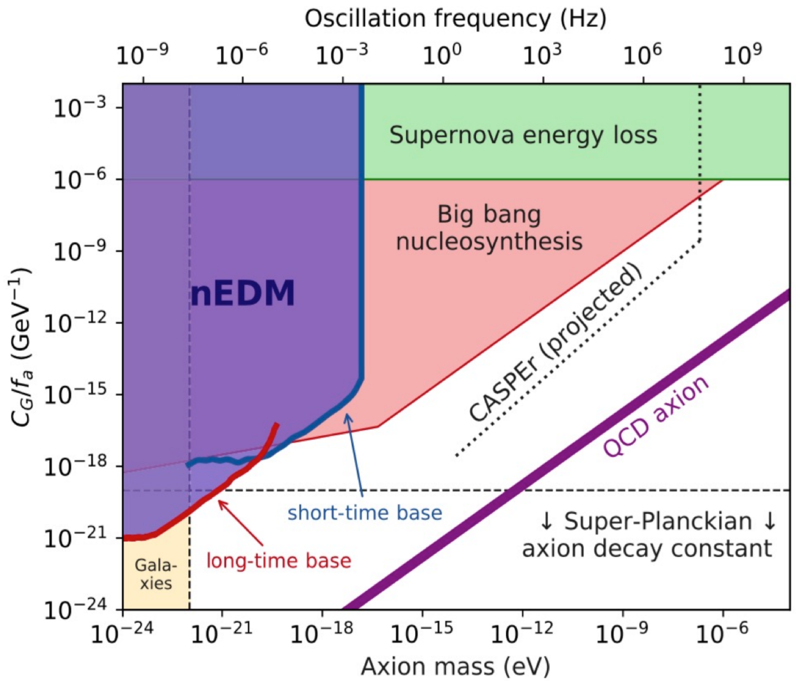
Measurements of both can discriminate among NP scenarios



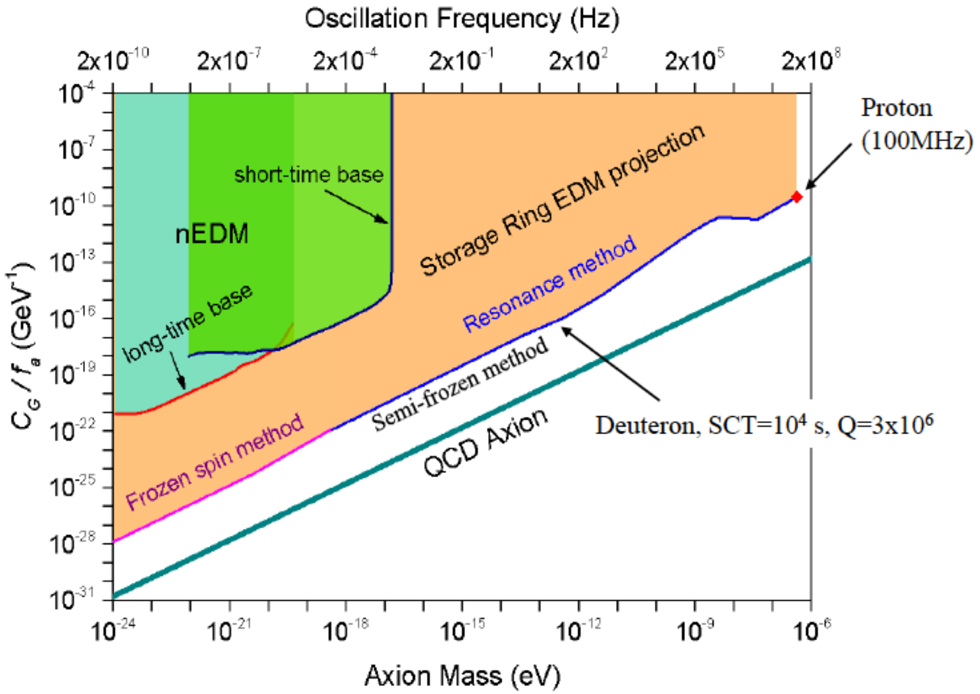
- Models with CKM-like flavor structure
  - Models with MFV
- Models with new flavor-violating interactions in which either LH or RH couplings dominate
  - *Z*/*Z'* models with pure LH/RH couplings
  - Littlest Higgs with *T* parity
- Models without above constraints
  - Randall-Sundrum

Axions with gluon coupling as DM candidates in sub-eV range

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



PHYSICAL REVIEW X 7, 041034 (2017)

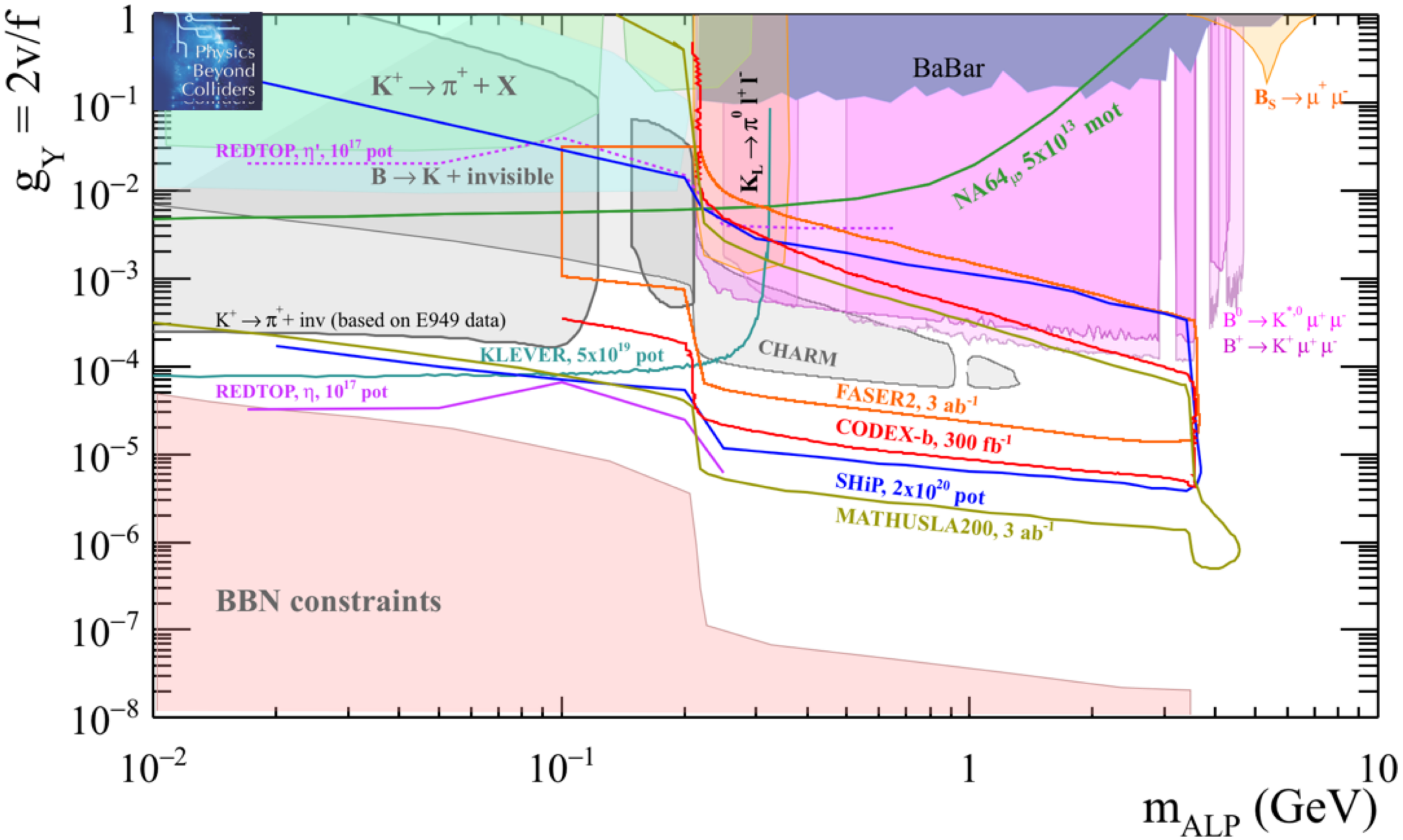


Y. Semerztidis, EDM workshop, CERN March 2018

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**

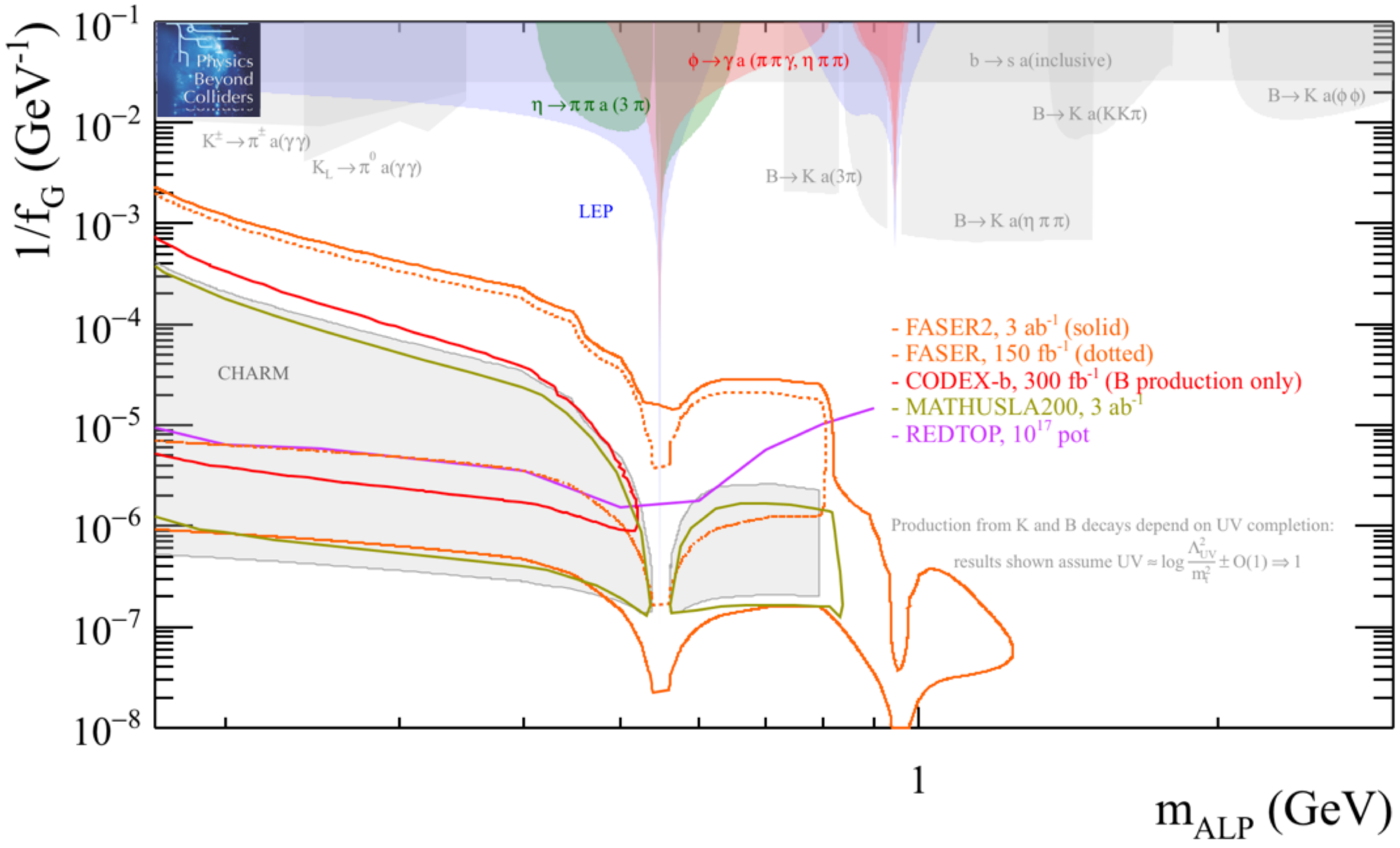
ALPS with fermion coupling in the MeV-GeV mass range

Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range
Need of a systematic investigation in the MeV-GeV range.



ALPS with gluon coupling in the MeV-GeV mass range

Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range
Need of a systematic investigation in the MeV-GeV range.

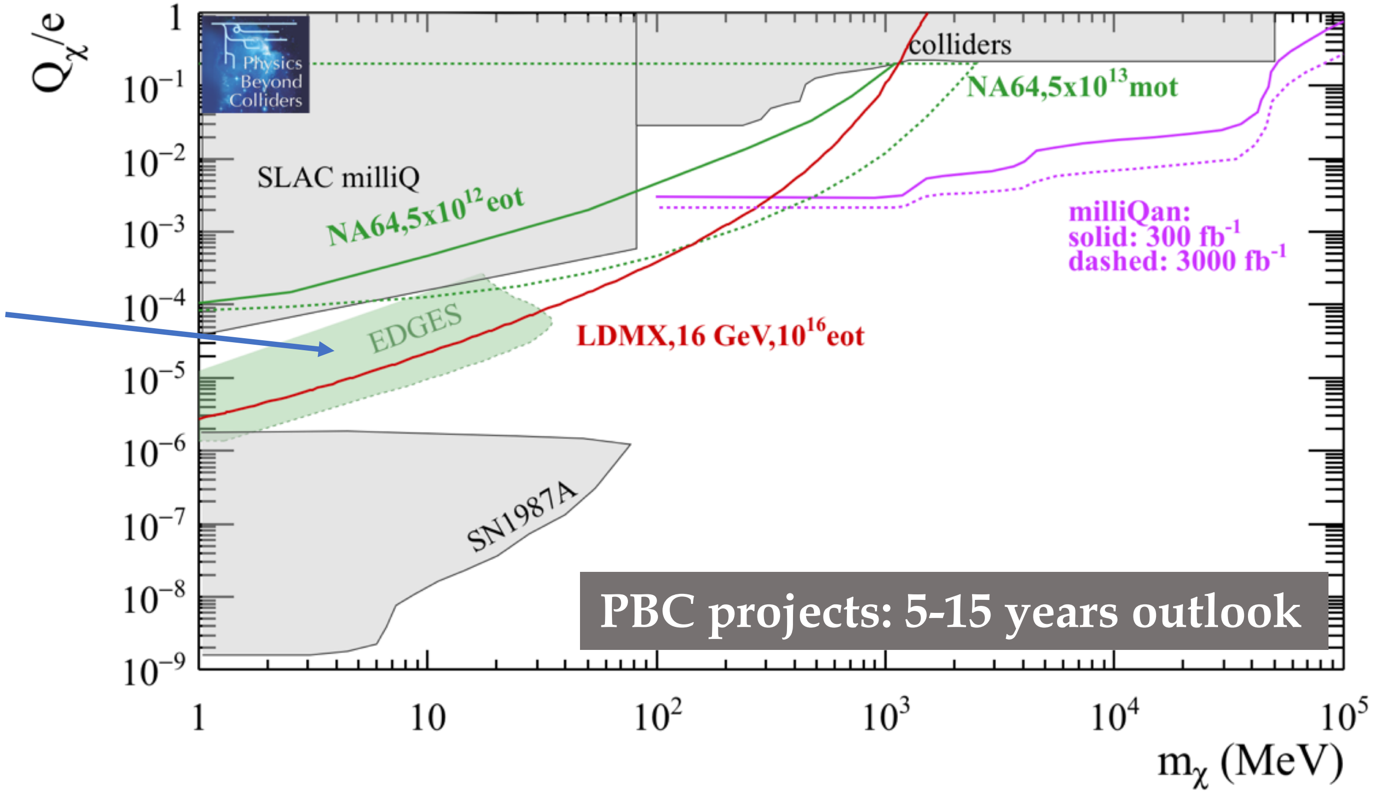


Milli-charged particles (Benchmark #3)

Milli-charged particles can be seen as a specific limit of the vector portal when $m_{A'}$ goes to zero and the parameter space simplifies to the mass ($m\chi$) and effective charge ($|Q| = |\varepsilon g_D e|$) of milli-charged particles.

CERN-PBC-REPORT-2018-007

The unexpected strength of 21 cm line anomaly signal measured by the EDGES radio-telescope could be naturally explained if (even only a fraction of) DM is in form of milliQ particles.



Nice complementarity with colliders and astrophysical data

Dark Scalar coupled to the Higgs (Benchmarks #4-5)

The Higgs portal 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.

Benchmark 5: assumes λ ≠ 0, namely BR(H->SS) ~ 1%.

CERN-PBC-REPORT-2018-007