Search for New Physics at the Intensity Frontier: the Physics Beyond Colliders activity @ CERN

Gaia Lanfranchi – CERN & INFN
In collaboration with:
C. Burrage, J. Jaeckel, M.Lamont, M. Pospelov, G. Ruoso, C. Vallee,
(+ experiments representatives)

Benasque, Spain, 9th April 2019

Experimental facts

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…..and nothing else

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- no new particles
- no (unambiguous) hint of NP in flavor
- no WIMP-like DM candidate

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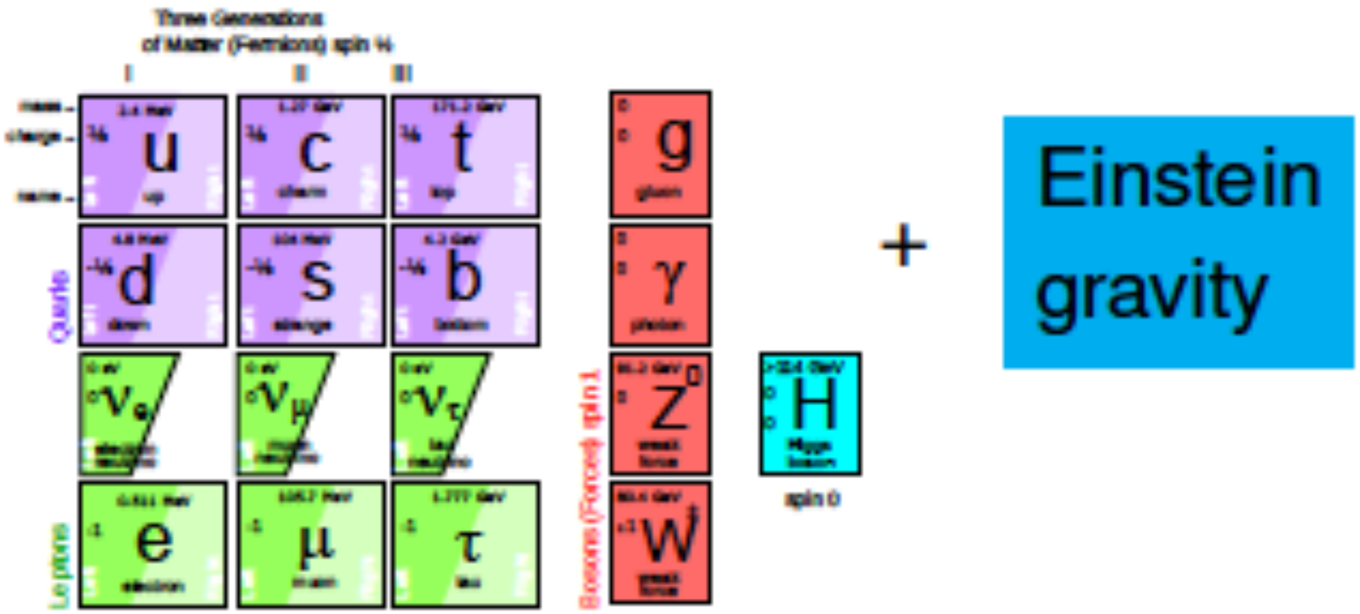
"Where is everybody?"

N Arkani-Hamed

The Standard Model is in excellent shape…

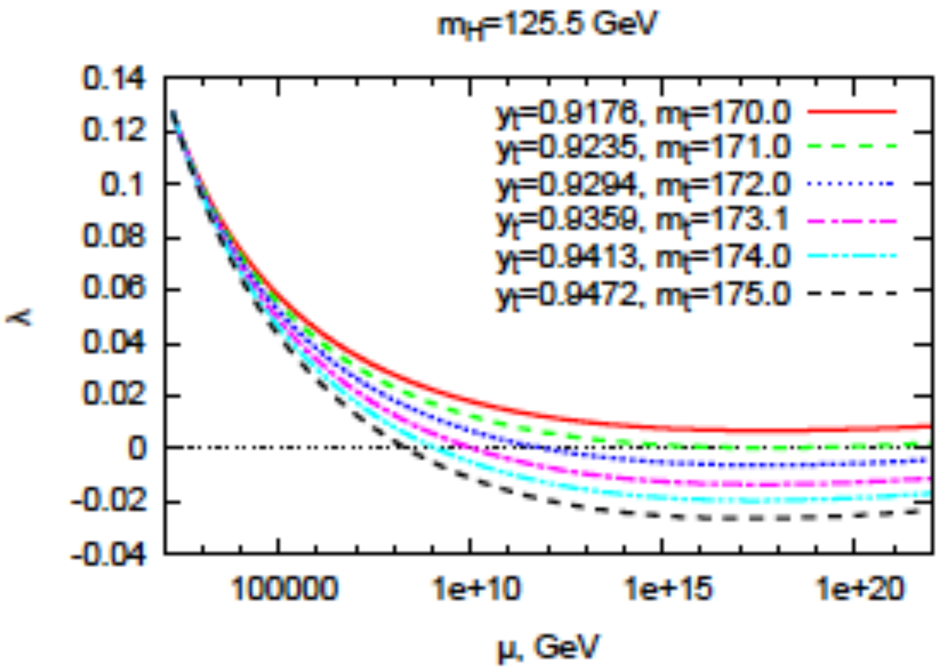


- ✓ SM works in all laboratory/collider experiments
- ✓ LHC 2012 – final piece of the model discovered: the Higgs boson
  - Mass measured   125 GeV –
  - Perturbative and predictive for high energies – mathematically consistent up the Planck scale
- ✓ Add gravity:
  - get cosmology
  - get Planck scale M_{Planck} = 1.22 10^{19} GeV as the highest energy to worry about.

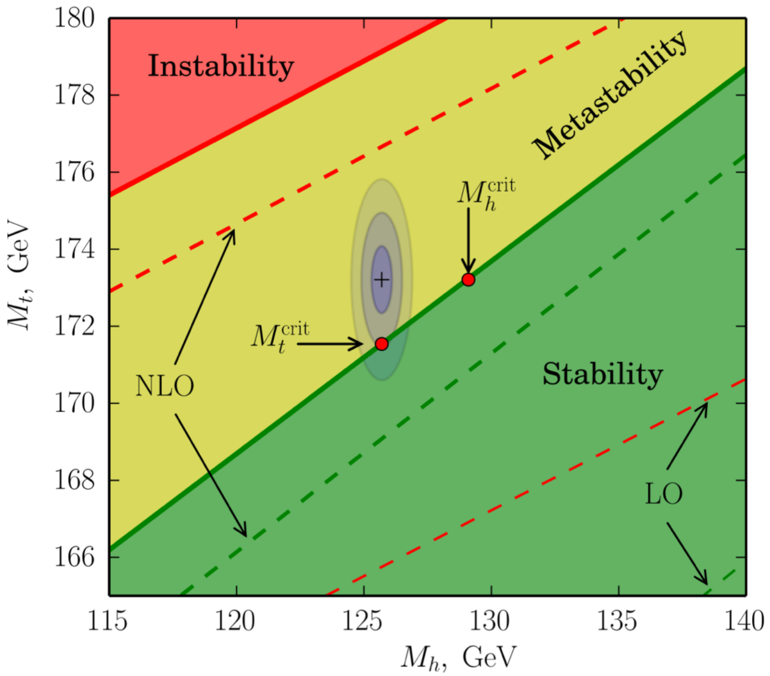
…and self-consistent up to the Planck scale !

M_H = 125.05 GeV and M_{top} = 173.1 GeV are two special numbers.

Coupling λ evolution:



Phase diagram of vacuum stability obtained at three loops (NNLO).



arXiv:1609.02503

the Standard Model is a self-consistent and (meta)-stable (effective) quantum field theory all the way up to the quantum-gravity Planck scale.

Is this the end of the story?

Experimental evidence for New Physics beyond the Standard Model

1) Observations of neutrino oscillations:
$\longrightarrow$ in the Standard Model neutrinos are massless and do not oscillate.

2) Evidence for Dark Matter
$\longrightarrow$ Standard Model does not have particle candidate for DM.

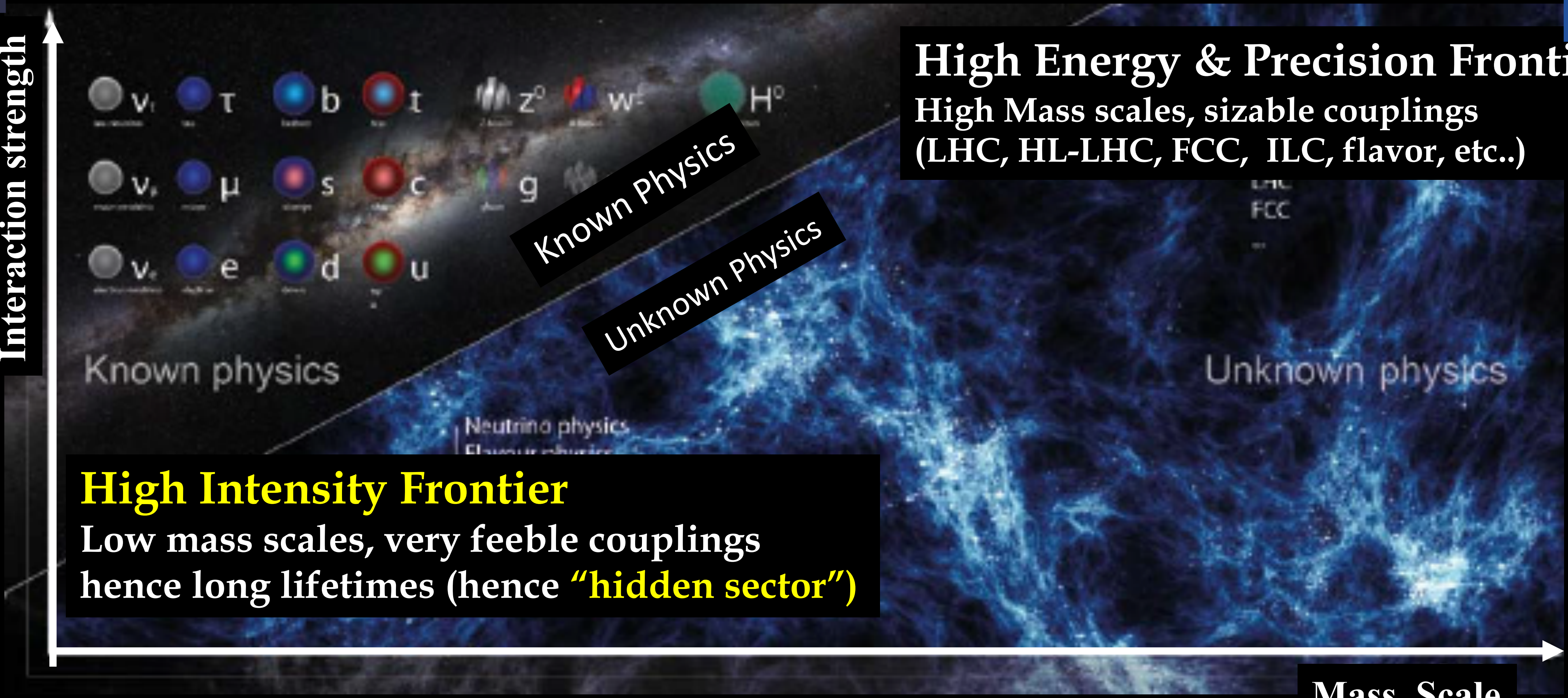
3) No antimatter in the Universe in amounts comparable with matter:
$\longrightarrow$ baryon asymmetry of the Universe is too small in the SM.

4) Cosmological inflation is absent in canonical variant of the SM.

5) Accelerated expansion of the Universe (?):
$\longrightarrow$ though can be "explained" by a cosmological constant.

Where to look for New Physics?

Search for New Physics at the Intensity Frontier



High Energy & Precision Frontier
High Mass scales, sizable couplings
(LHC, HL-LHC, FCC, ILC, flavor, etc..)

High Intensity Frontier
Low mass scales, very feeble couplings
hence long lifetimes (hence "hidden sector")

"Many TeV-scale ideas/models have been scrutinized
Need a systematic investigation of the High Intensity Frontier"

The Physics Beyond Colliders activity @ CERN

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

The mandate:

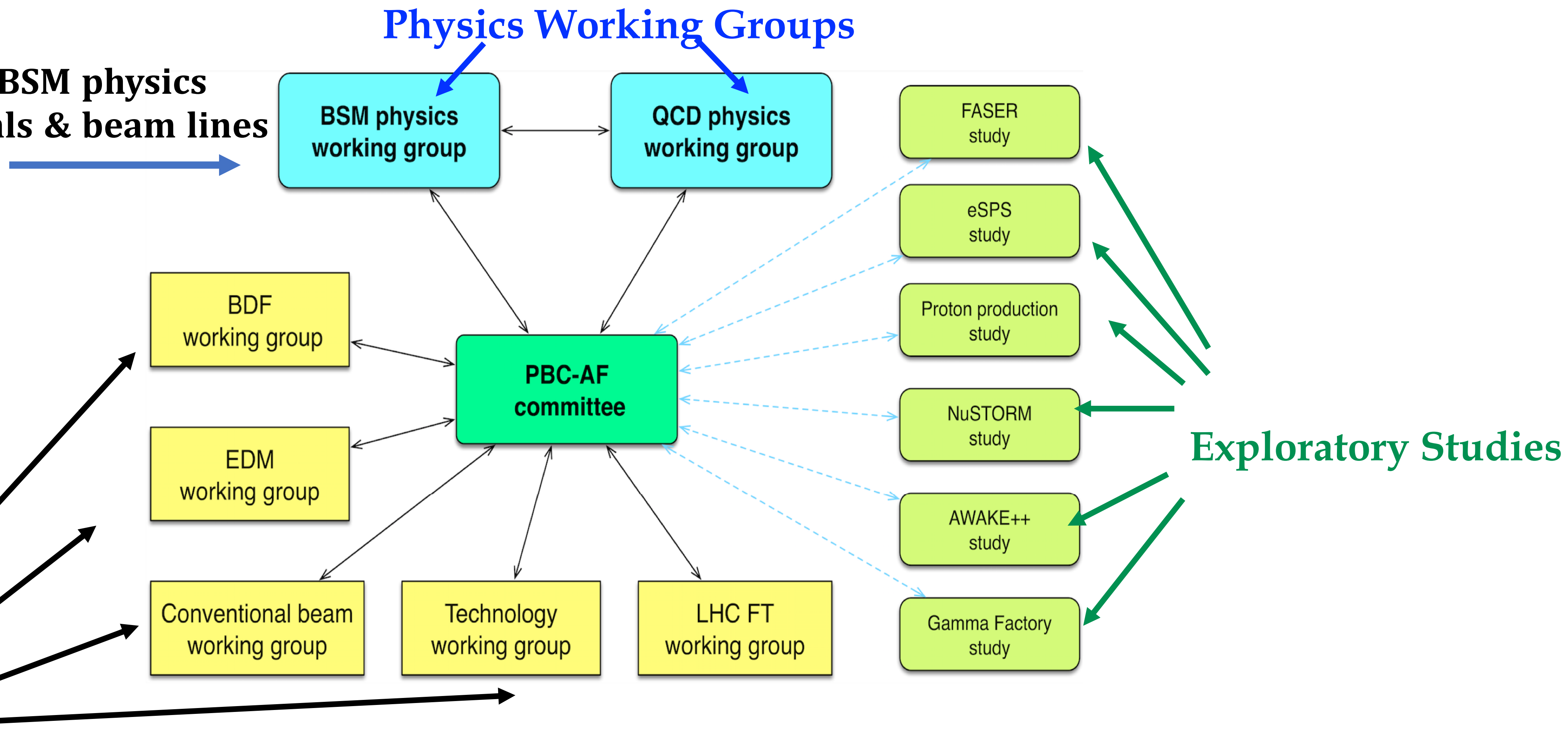
"Physics Beyond Colliders is an exploratory study aimed at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure through projects complementary to the LHC, HL-LHC and other possible future colliders. These projects would target fundamental physics questions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

Deliverables for the European Strategy Update:

- PBC summary report – arXiv: 1902.00260
- QCD WG Report – arXiv:1901.04482
- BSM WG Report – arXiv: 1901.09966 (most of the material of this talk)
- Experiments' proposals & beam lines Yellow Reports (~15 inputs to ESU)

Physics Beyond Colliders Structure

Today: focus on BSM physics and related proposals & beam lines



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

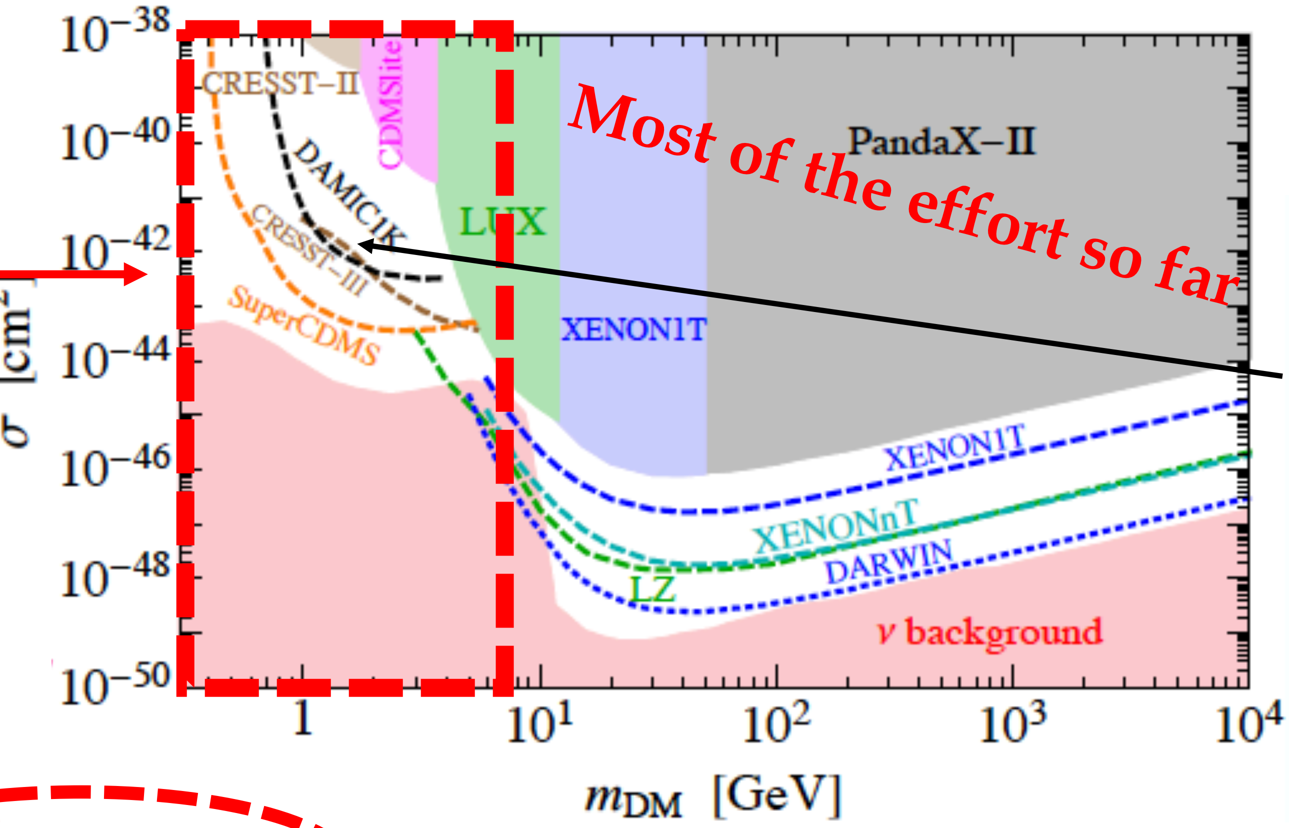
Physics Beyond Colliders

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)

< 10 keV DM too hot, spoils structure formation

$\sim m_e$ — **1 MeV**

LDM

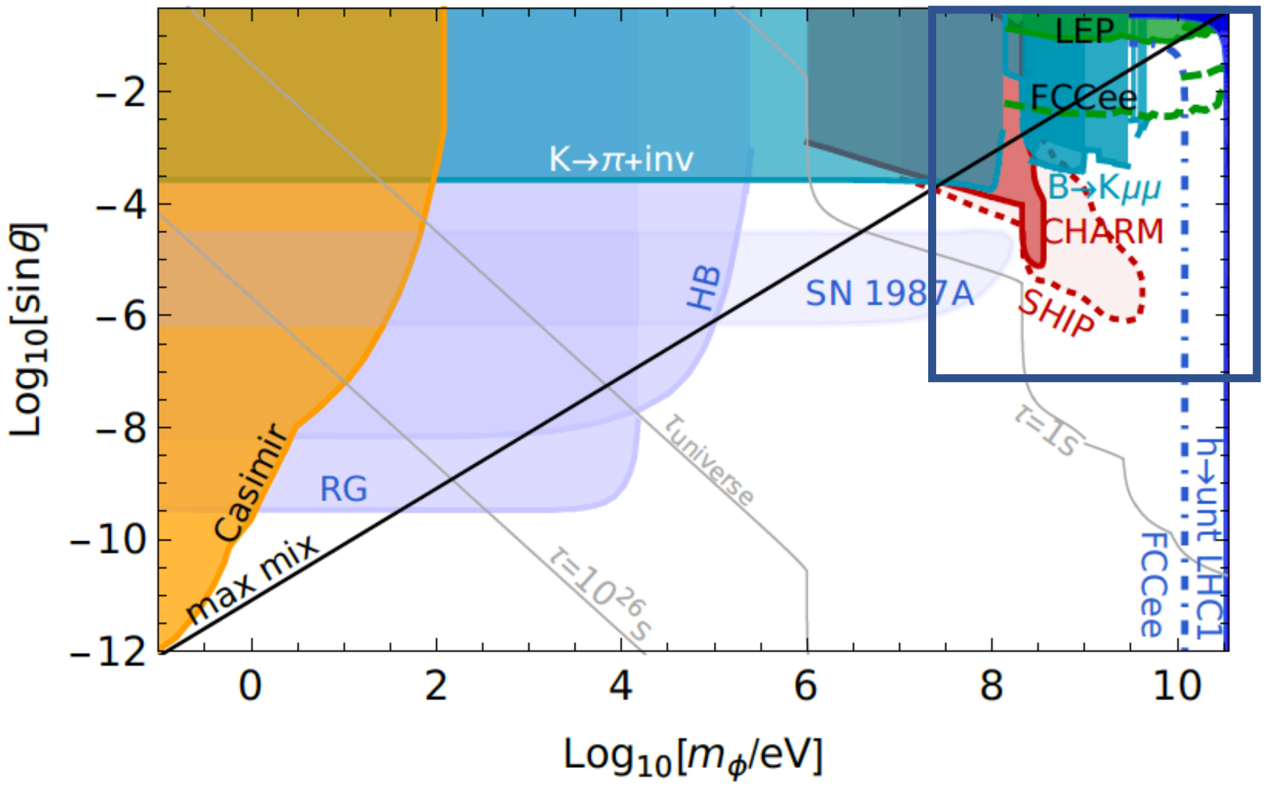
$\sim m_p, m_n$ — **1 GeV**

WIMPs paradigm — **M_Z**

> 100 TeV DM overproduced — **10 TeV**

PBC target: “heavy” relaxion/scalar-portal

Light feeble goldstone boson, may stabilize the Higgs mass against radiative corrections (relaxion mechanism).



MeV-GeV range

PBC target

No scale associated.
We need a multi-scale approach.

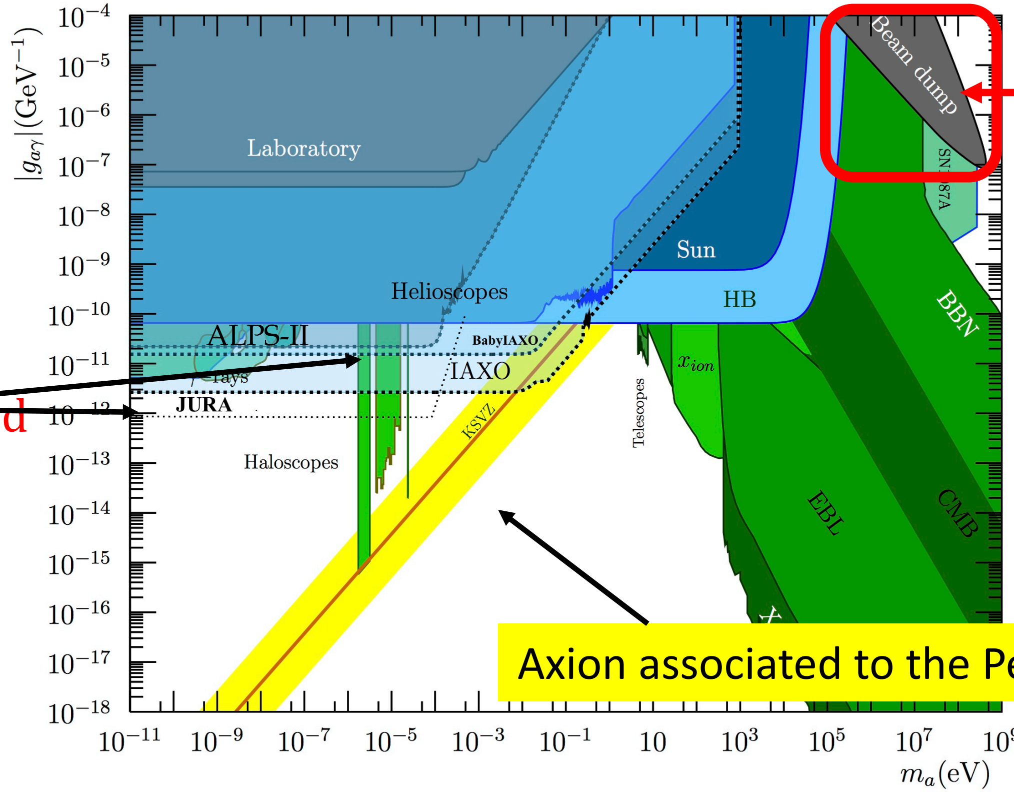
PBC target: Axion and Axion-Like Particles

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



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

PBC target

Axion associated to the Peccei-Quinn symmetry

No scale associated: we need a multi-scale approach.

PBC target: (Light) Right-Handed Neutrinos

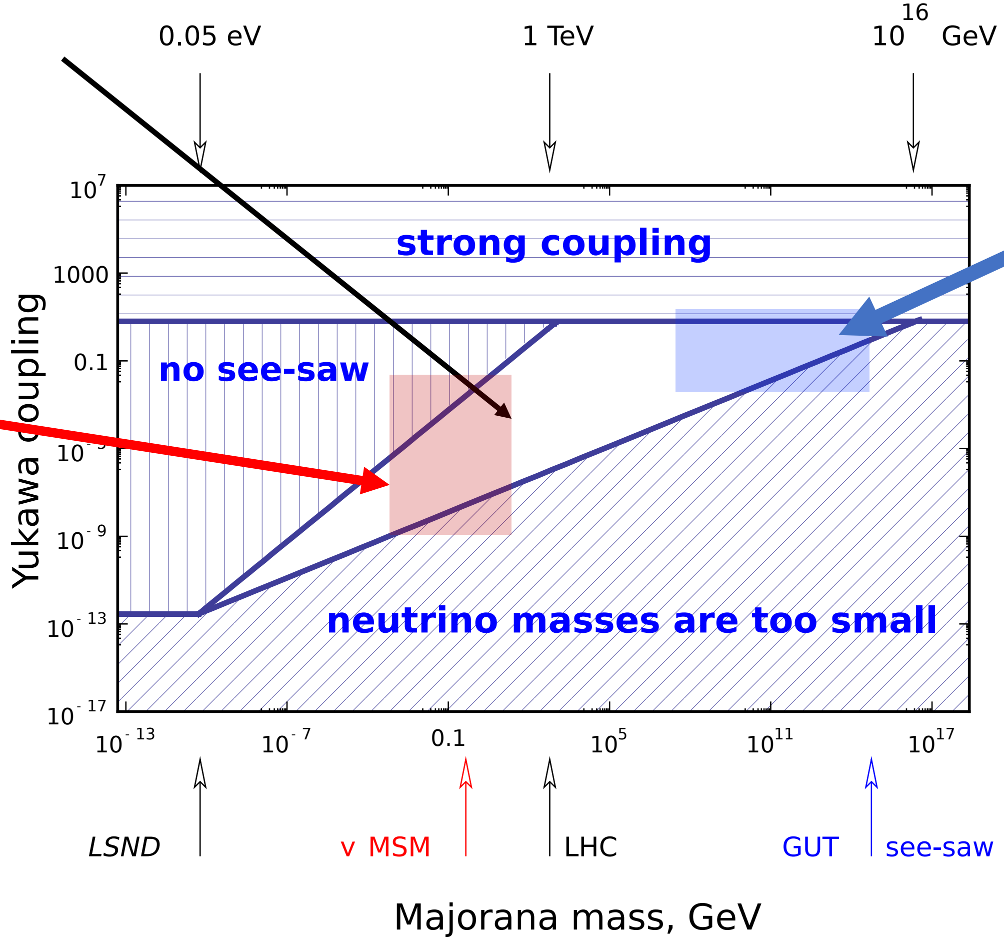
Right handed neutrinos responsible of the neutrinos' mass generation can have any coupling/mass in the white area, assuming a soft U(1)_L breaking

PBC target

Alternative choice: EW "see-saw" (νMSM)

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

If 2 RHN have a mass degeneracy of o(10^{-2}) they could also explain baryogenesis via leptogenesis



Standard choice: GUT see-saw

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

Large spectrum of masses possible. We need a multi-scale approach.

Physics Beyond Colliders Projects (BSM)

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 LDM, HNLs, lepto-phobic DM, ..	BDF, SPS	400 GeV p	$2 \cdot 10^{20}$/5 years
NA62^{++}	ALPs, Dark Photons, Dark Scalars, HNLs	K12, SPS	400 GeV p	up to $3 \cdot 10^{18}$/year
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	$+ L_\mu - L_\tau$	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
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CODEX-b	Dark Scalar, HNLs, ALPs, LDM, Higgs decays	LHCb IP	14 TeV p	300 fb^{-1}
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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

arXiv: 1901.09966

A multi-scale approach.

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Non Accelerator-based

Accelerator-based

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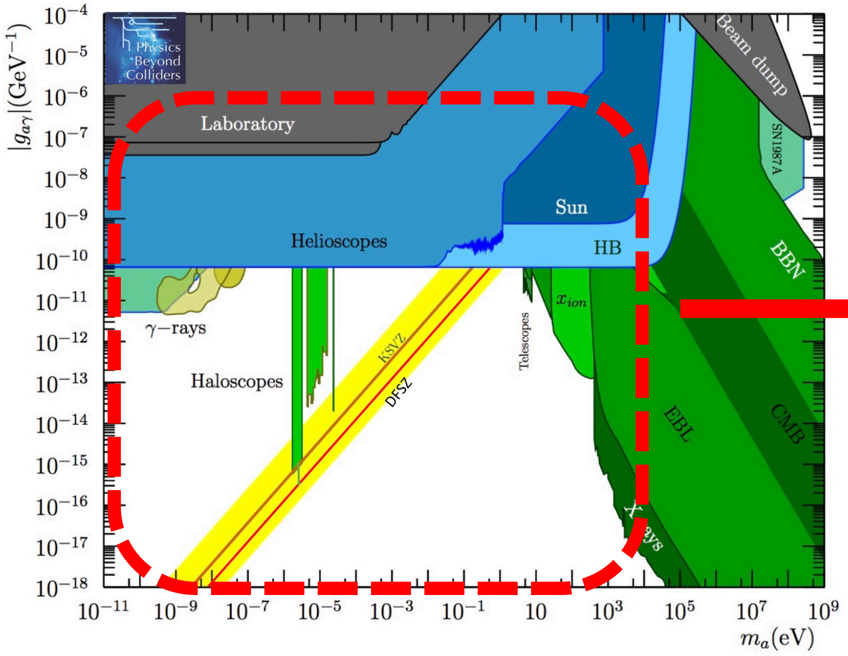
A multi-scale approach.

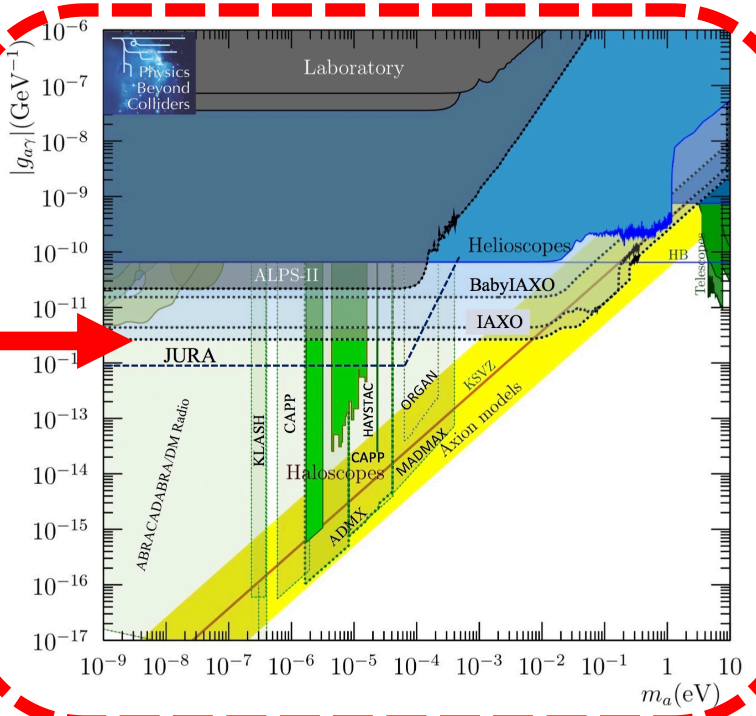
Axions and ALPs with photon coupling

Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range.

1901.09966

zoom in the sub-eV range





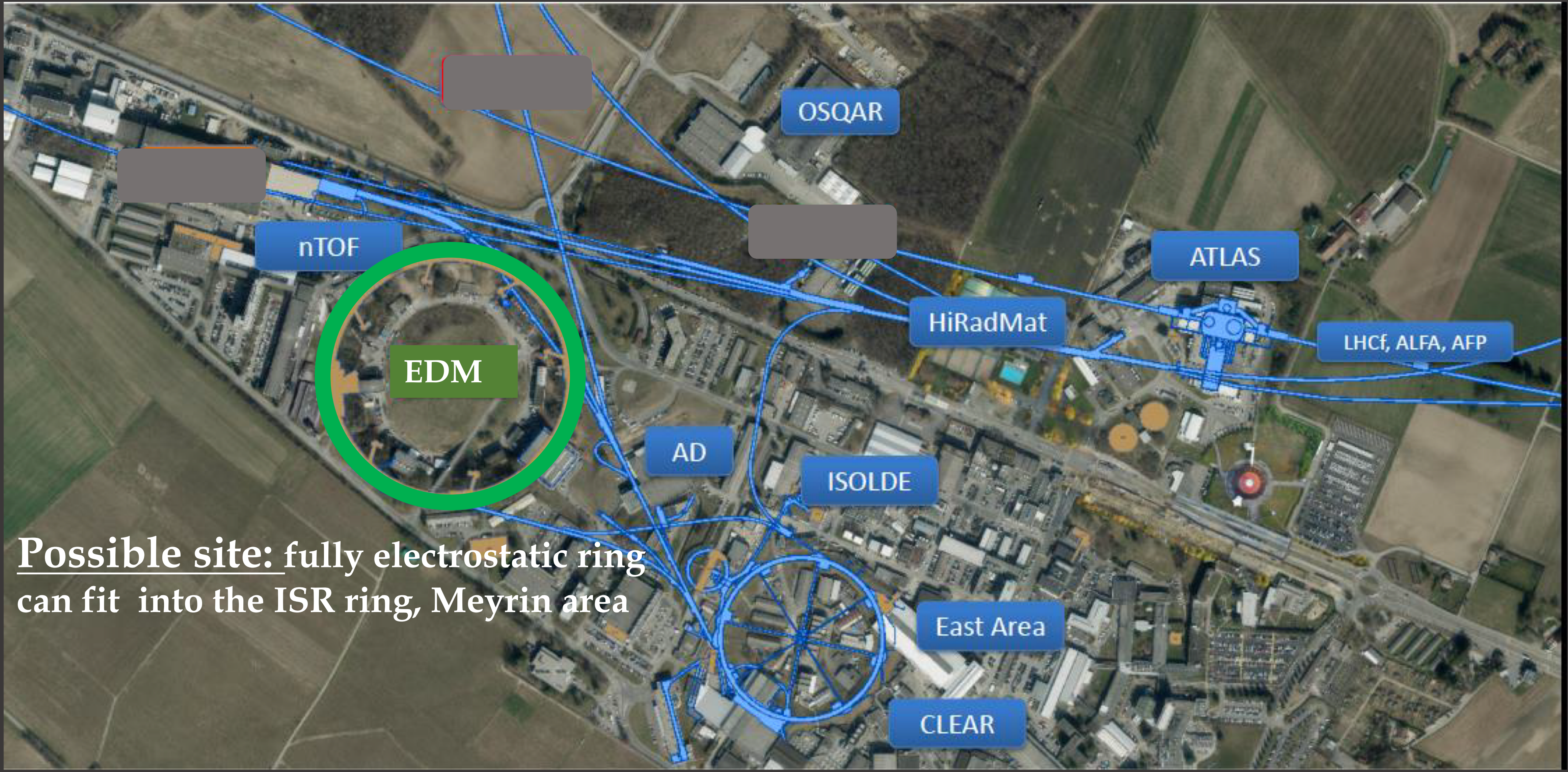
IAXO and JURA mostly considered in the Technology WG for support in:

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

Extremely lively field in the sub-eV range (many projects ongoing)
(see I. Irastorza's talk yesterday morning)

Proton and Deuteron EDMs:

search for new sources of CPV in the sub-eV (oscillating 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 (oscillating 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 recognized to be very challenging.

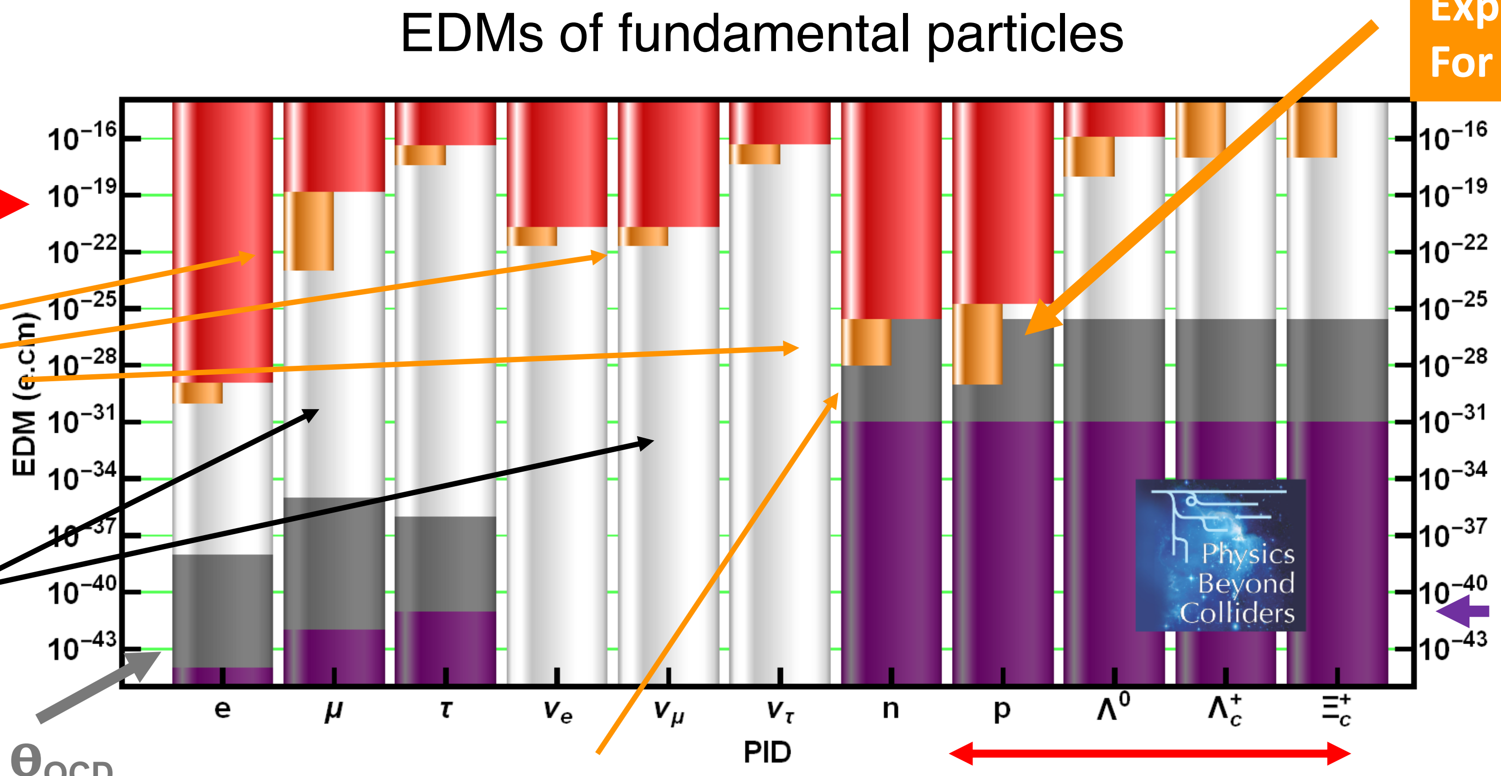
Axions and ALPS with gluon coupling as probes of the multi-TeV range

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.

Expected sensitivity For the CP-EDM project

Current limits on EDMs of fundamental particles;

Expected improvements in the next o(10-20) years



White regions: safe BSM discovery territory;

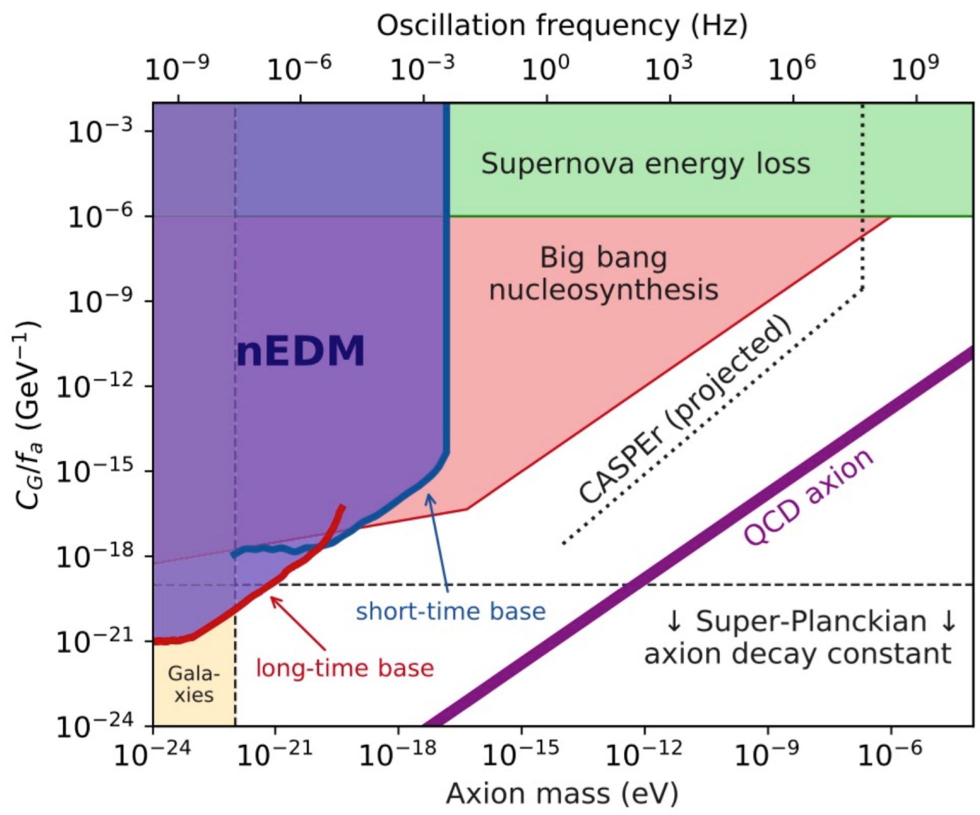
SM estimates from θ_{QCD}

SM estimates from CKM CP violation

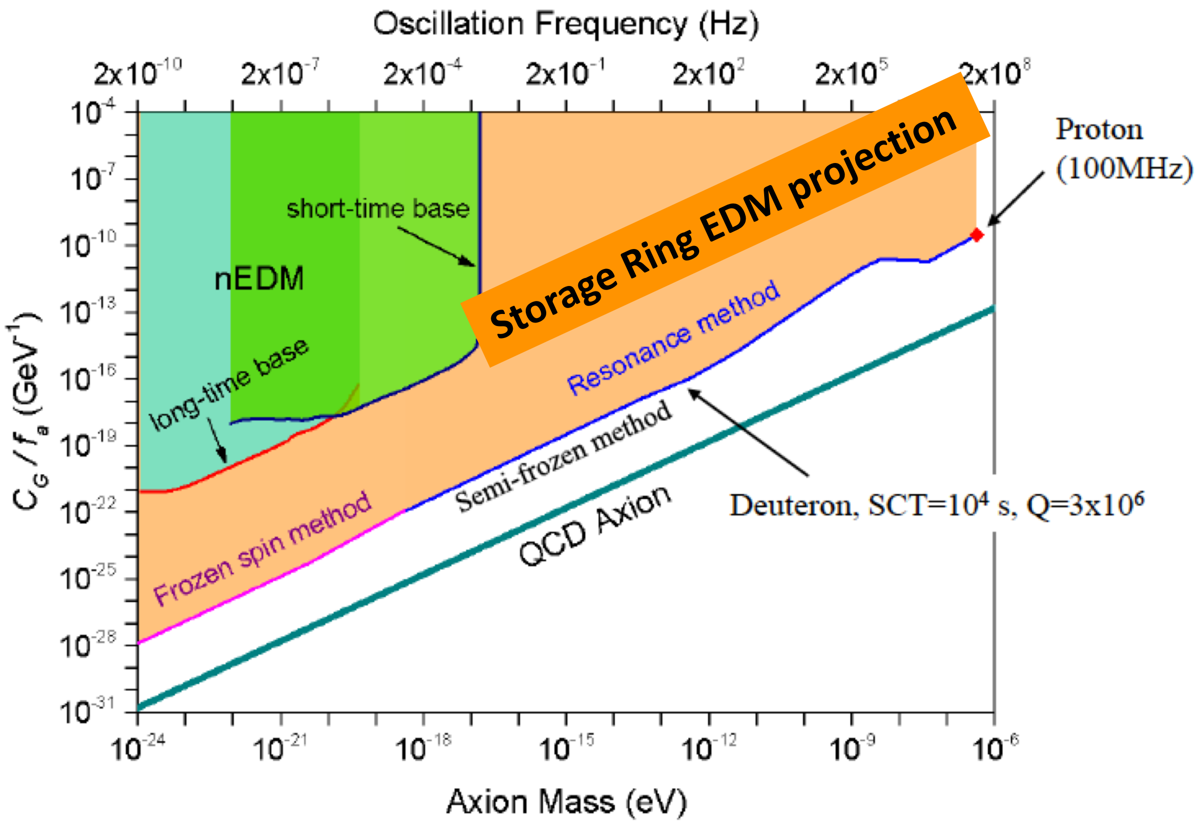
Neutron EDM is leading the field for hadrons

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

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**

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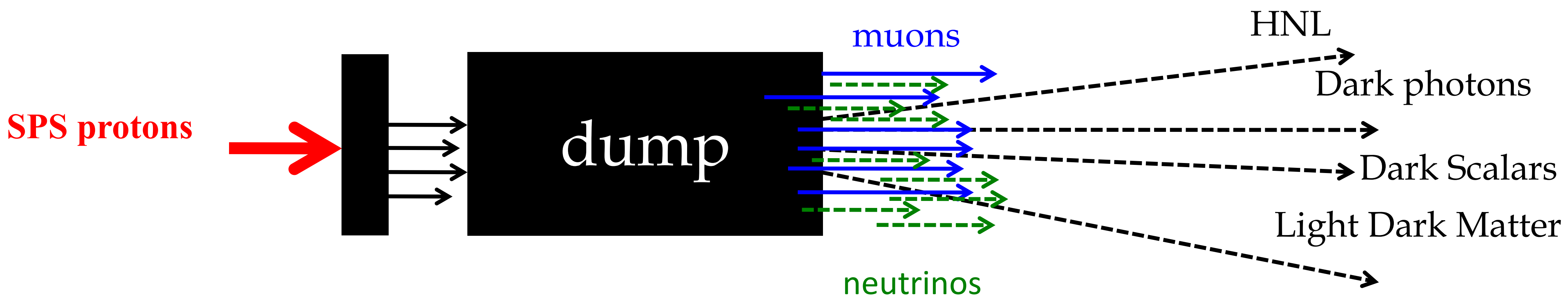
Non Accelerator-based

Accelerator-based

arXiv: 1901.09966

A multi-scale approach.

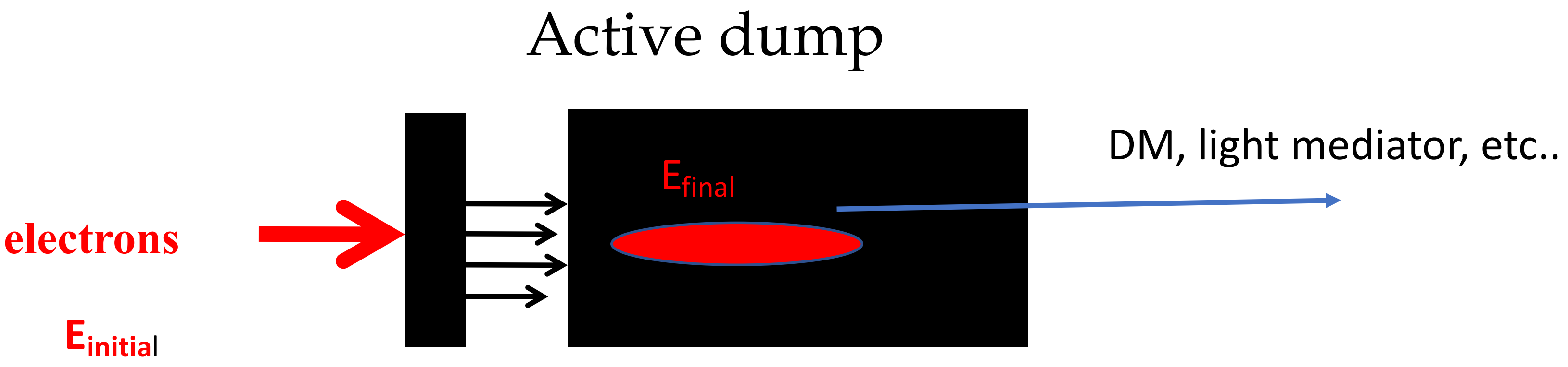
Search for long-lived particles in the MeV-GeV range: “DUMP” experiments



Beam Dump Technique.

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

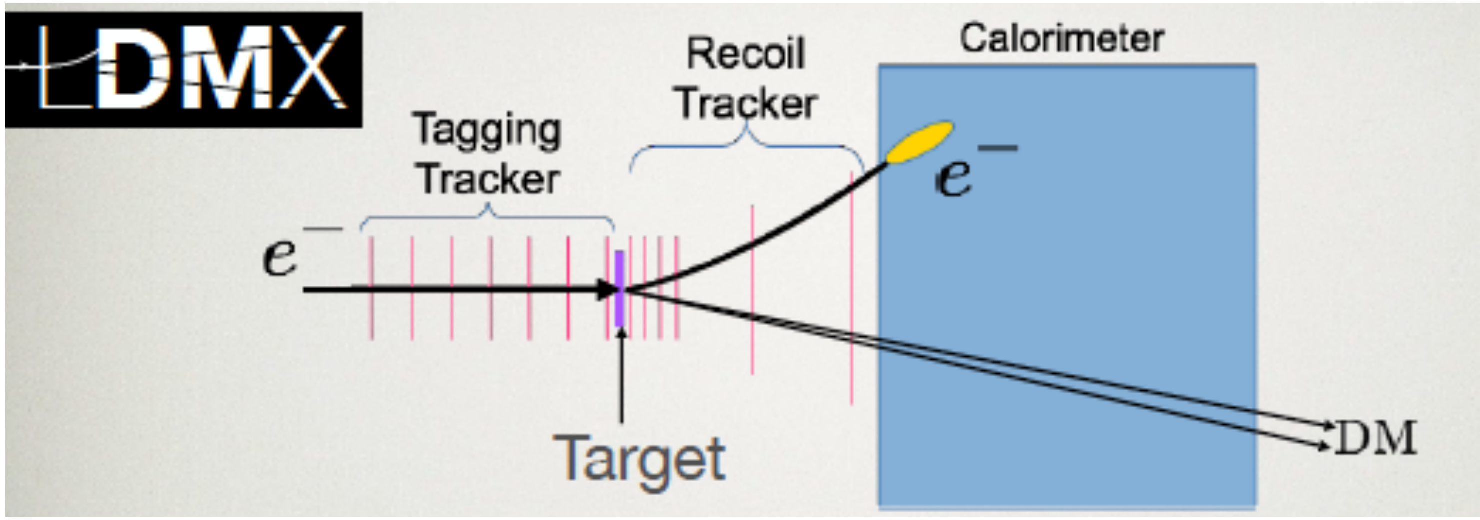


Missing Energy technique.

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

Missing momentum:

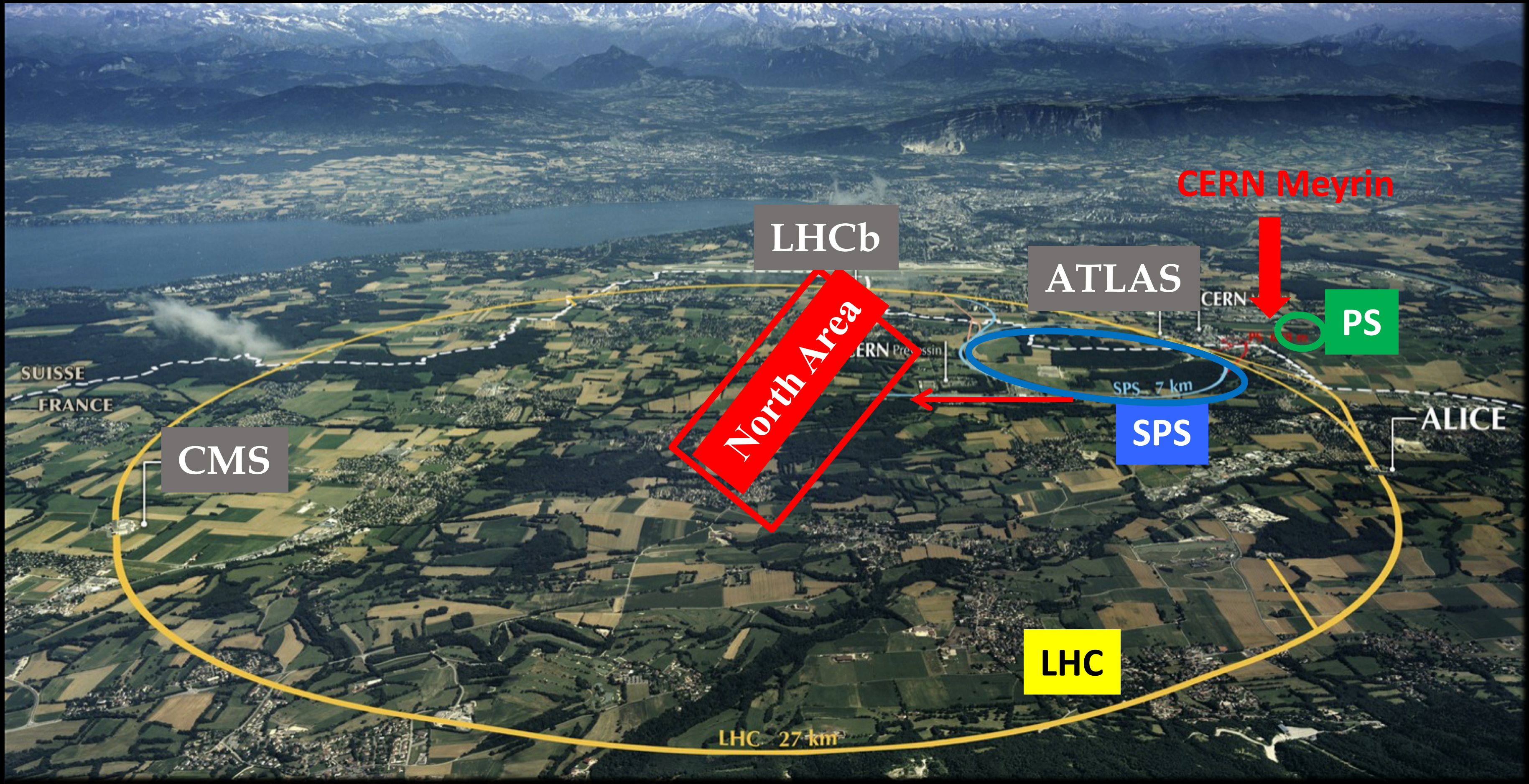
any discrepancy between the momentum of the electron/muon measured before and after the target would be sign of the production of some non-interacting particle, as for example Dark Matter



Missing momentum technique

The CERN Accelerator Complex and Sites

Feebly interacting long-lived particles require high-energy high-intensity beams



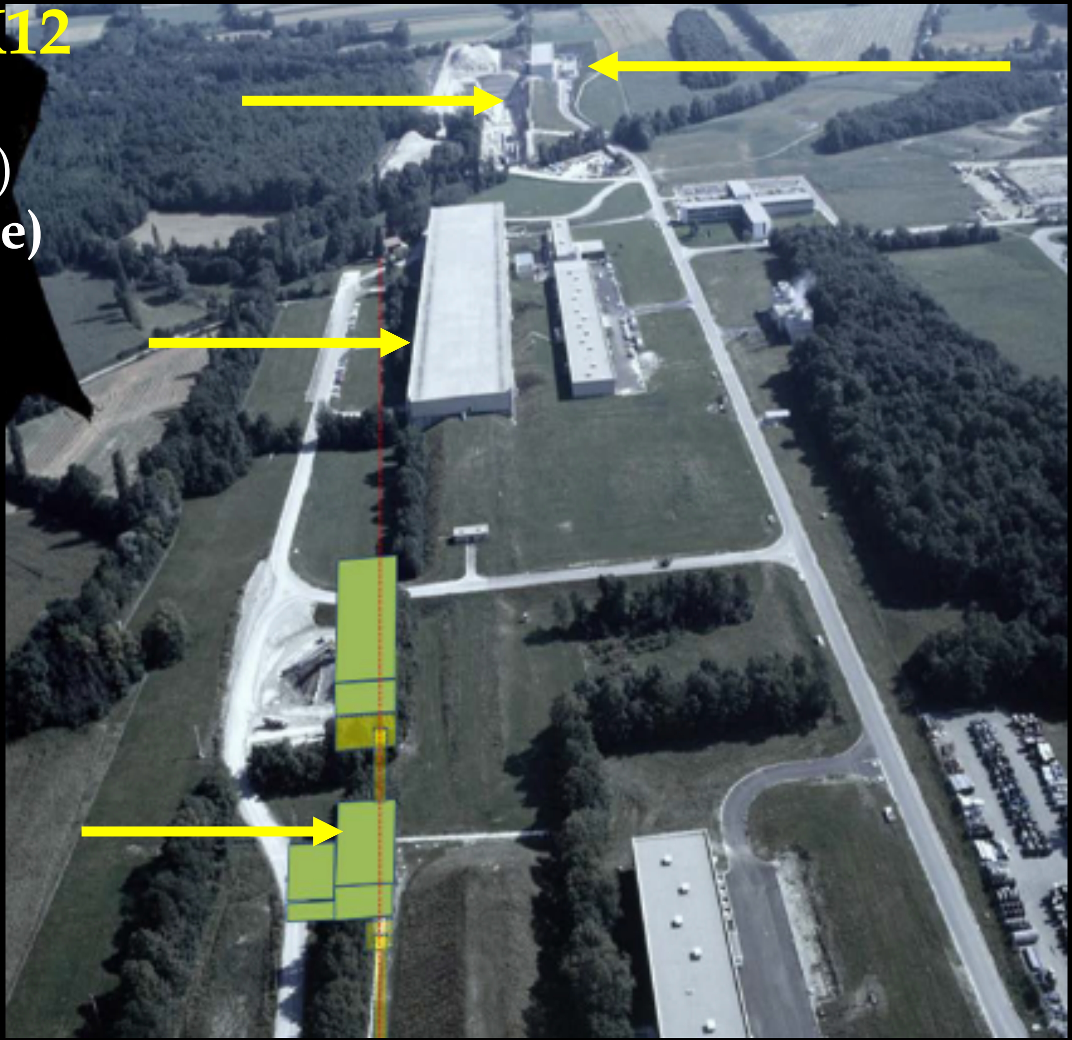
CERN can provide the highest energy proton, electron and muon beams in the world.

(some) PBC Proposals in the North Area

NA62 $^{++}$, KLEVER @ K12
400 GeV p beam
up to 3×10^{18} pot/year (now)
up to 10^{19} pot/year (upgrade)

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

SHiP, TauFV @ BDF
400 GeV p
up to 4×10^{19} pot/year

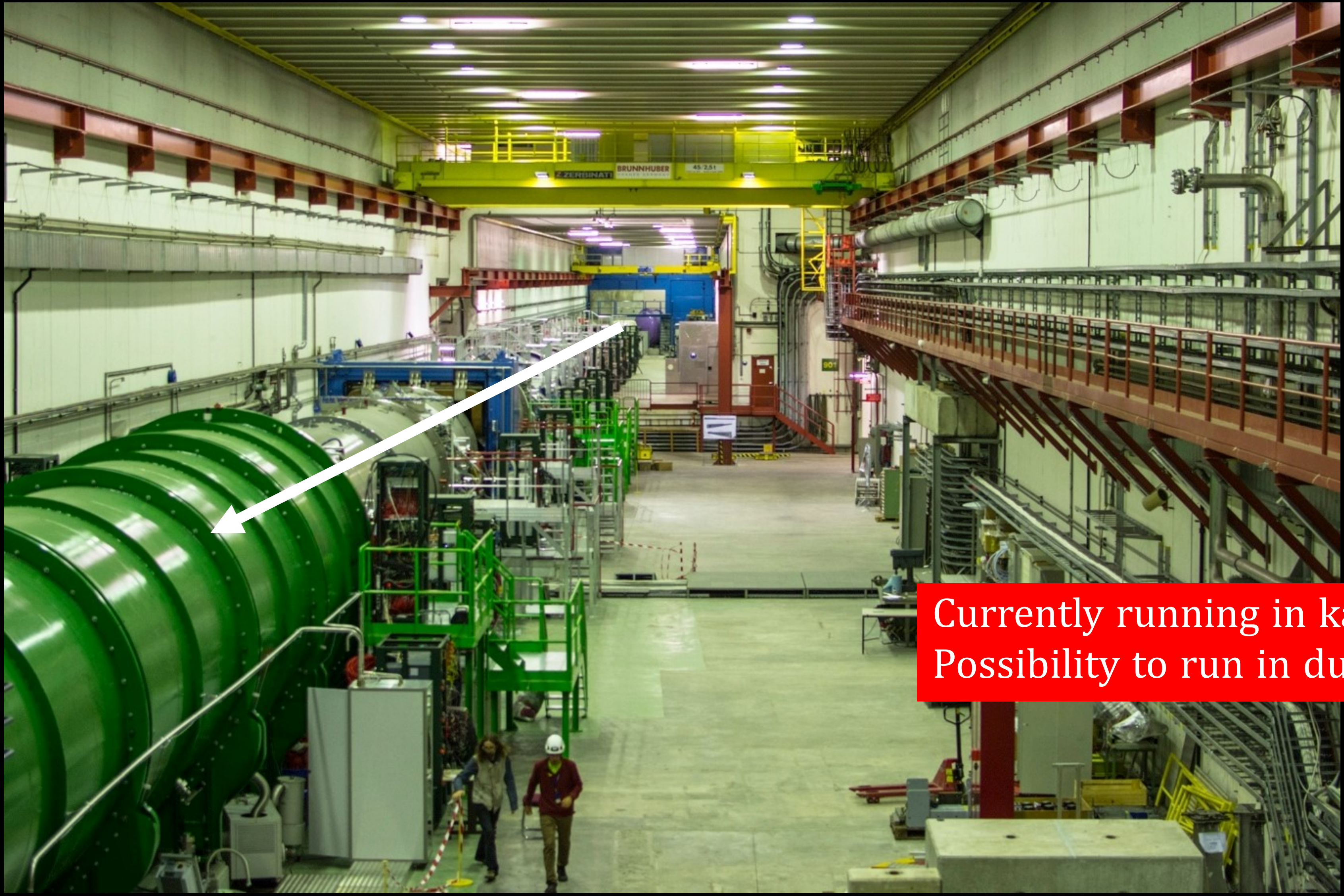


NA64^{++} (μ) @ M2
100-160 GeV muons,
up to 10^{13} μ/year

The "Hidden Sector Campus" (HSC)

The NA62 experiment @ K12 in EHN3

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



Beam Dump technique

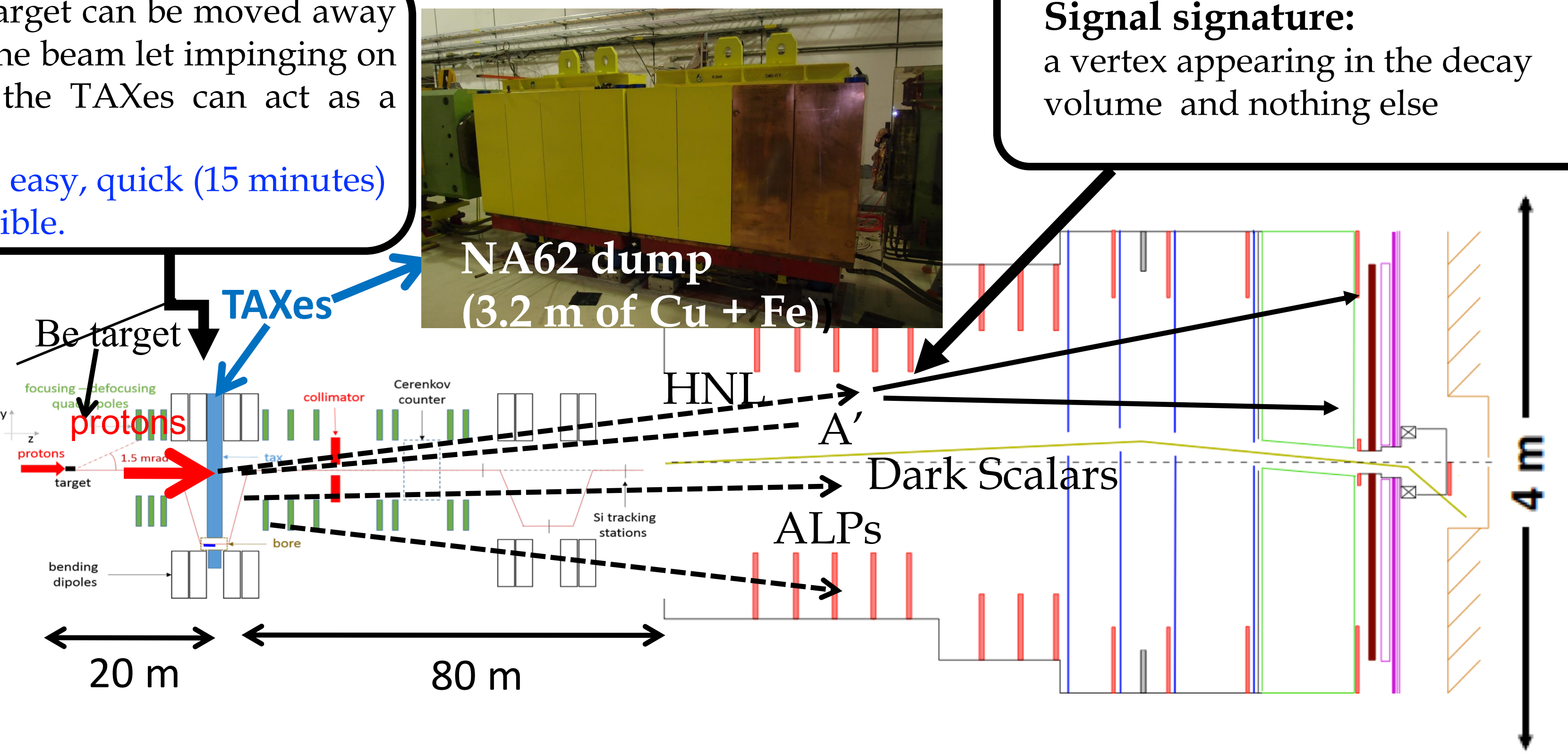
Currently running in kaon mode
Possibility to run in dump-mode in 2023

NA62 in "dump" mode (2023++)

NA62 currently running in K12. Will (likely) 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



The NA64 experiment in EHN1, H4

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

Active Dump technique

Approved in 2016.
Currently running in electron mode.
Aim at running in muon mode in Run 3-4.

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

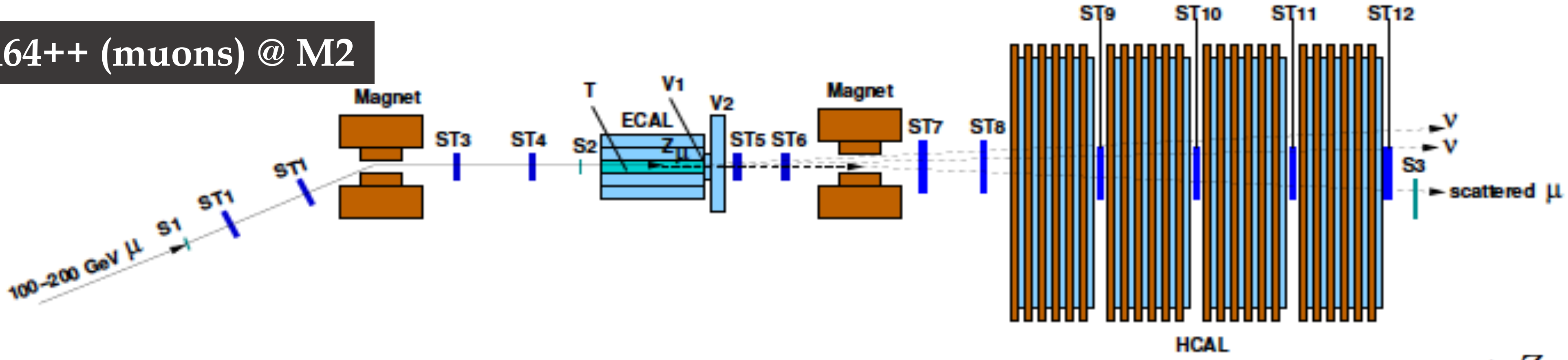
Proposal to extend the physics programme after LS2:

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.

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

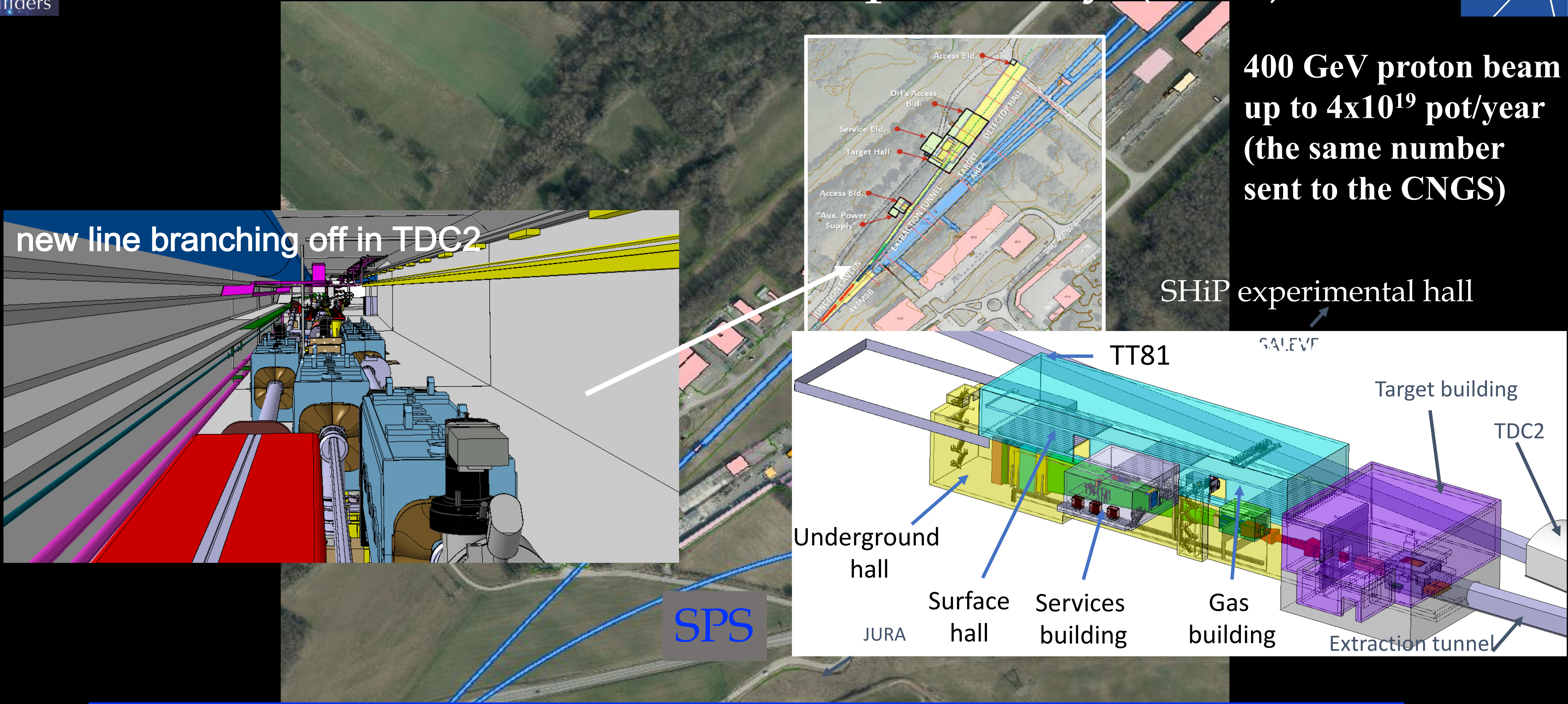
NA64++ (muons) @ M2



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

(Dark sector coupled to the second generation)

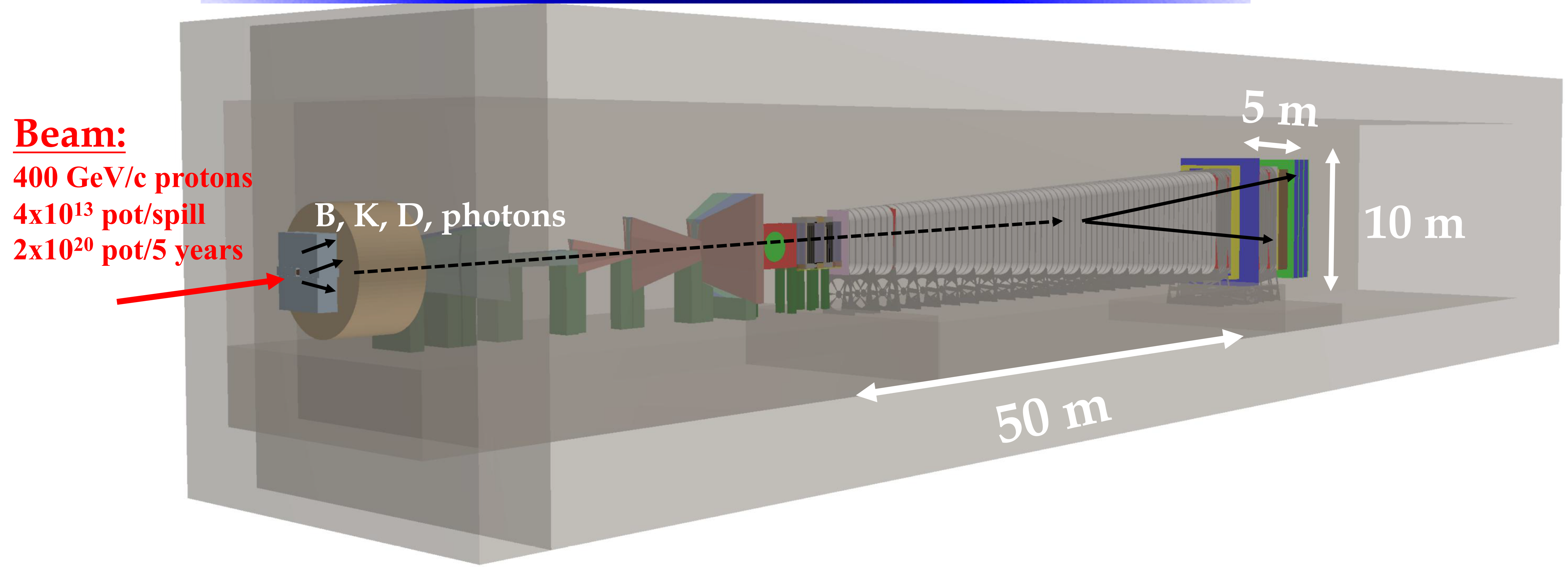
SHiP at the Beam Dump Facility (BDF)



400 GeV proton beam up to 4x10^{19} pot/year (the same number sent to the CNGS)

Brand new high-intensity proton beamline proposed in the North Area
~500 pp Yellow Report in preparation.

SHiP @ BDF

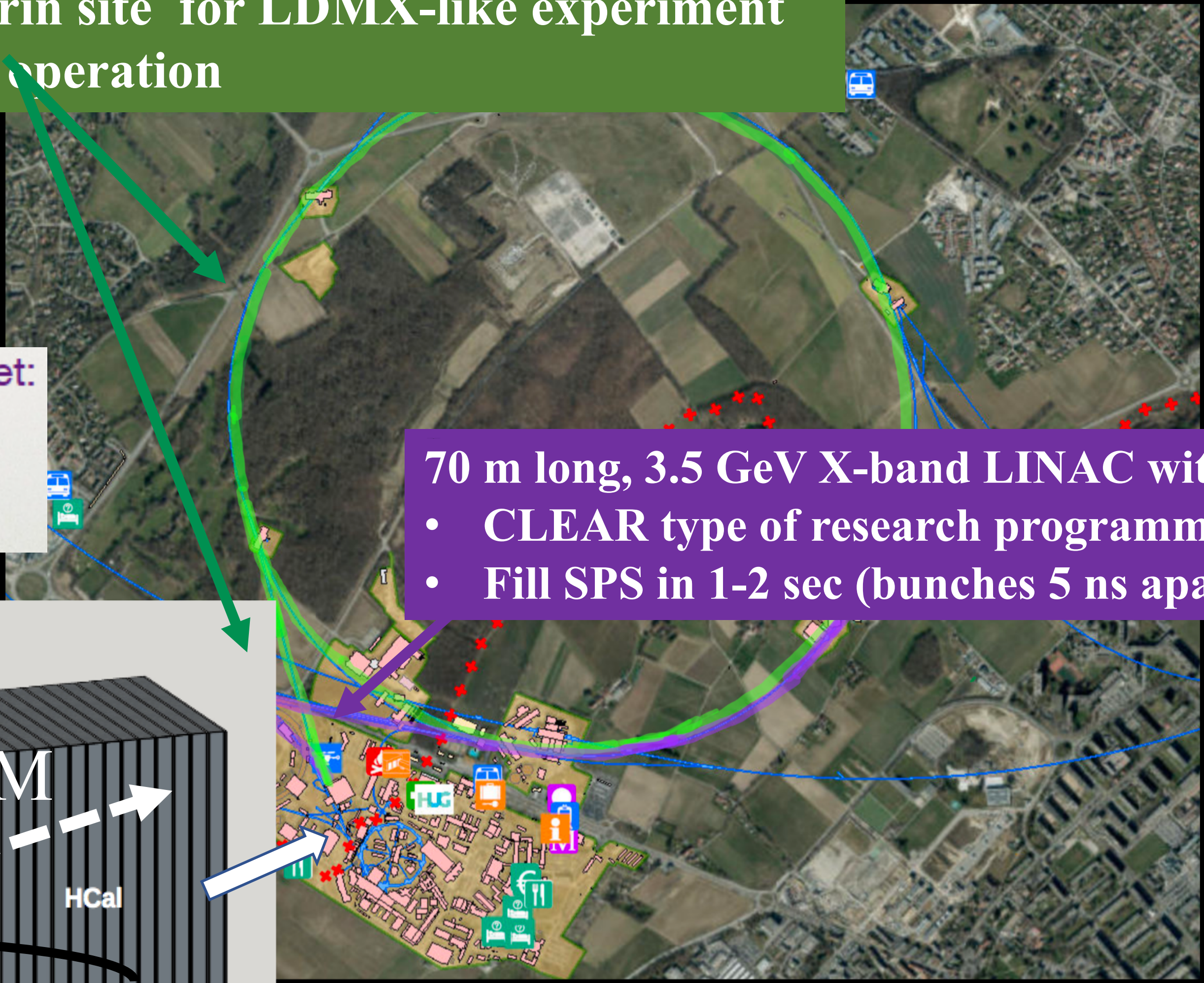


- ✓ Hidden particles have very feeble couplings, hence they are (very) long-lived:
  - The 60m-long, in-vacuum SHiP decay volume allows us to be sensitive to extremely low couplings
- ✓ Hidden particles from D and B decays have large p_T:
  - SHiP large geometrical acceptance maximizes detection of decay products

LDMX @ eSPS: Meyrin area

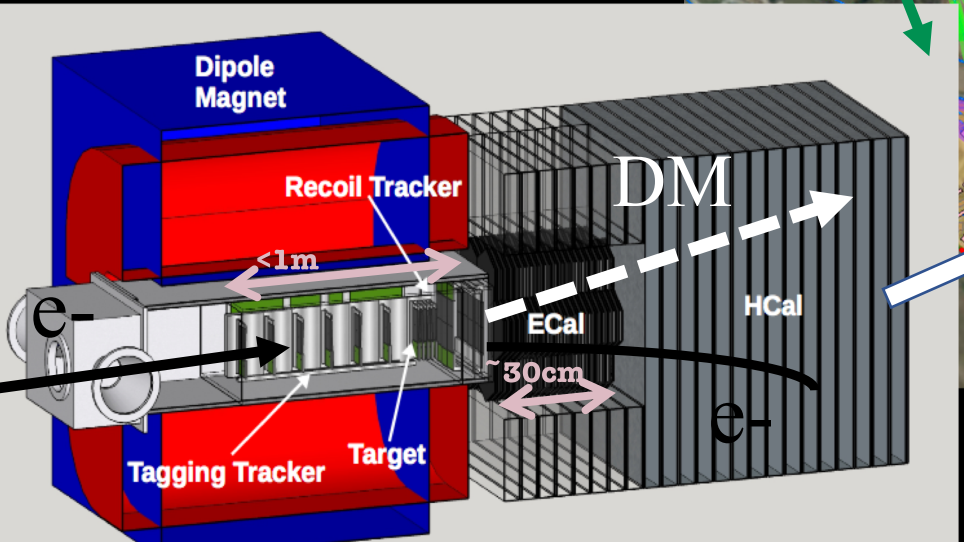
GREEN: ~16 GeV electron beam in SPS
slow extraction towards Meyrin site for LDMX-like experiment
Up to 10^{16} eot in o(1) year of operation

Missing momentum technique



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;**

Electron beam impinging on target:
- multi-GeV electrons
- 1-200 MHz bunch spacing
- Ultra-low O(1-5) electrons per bunch



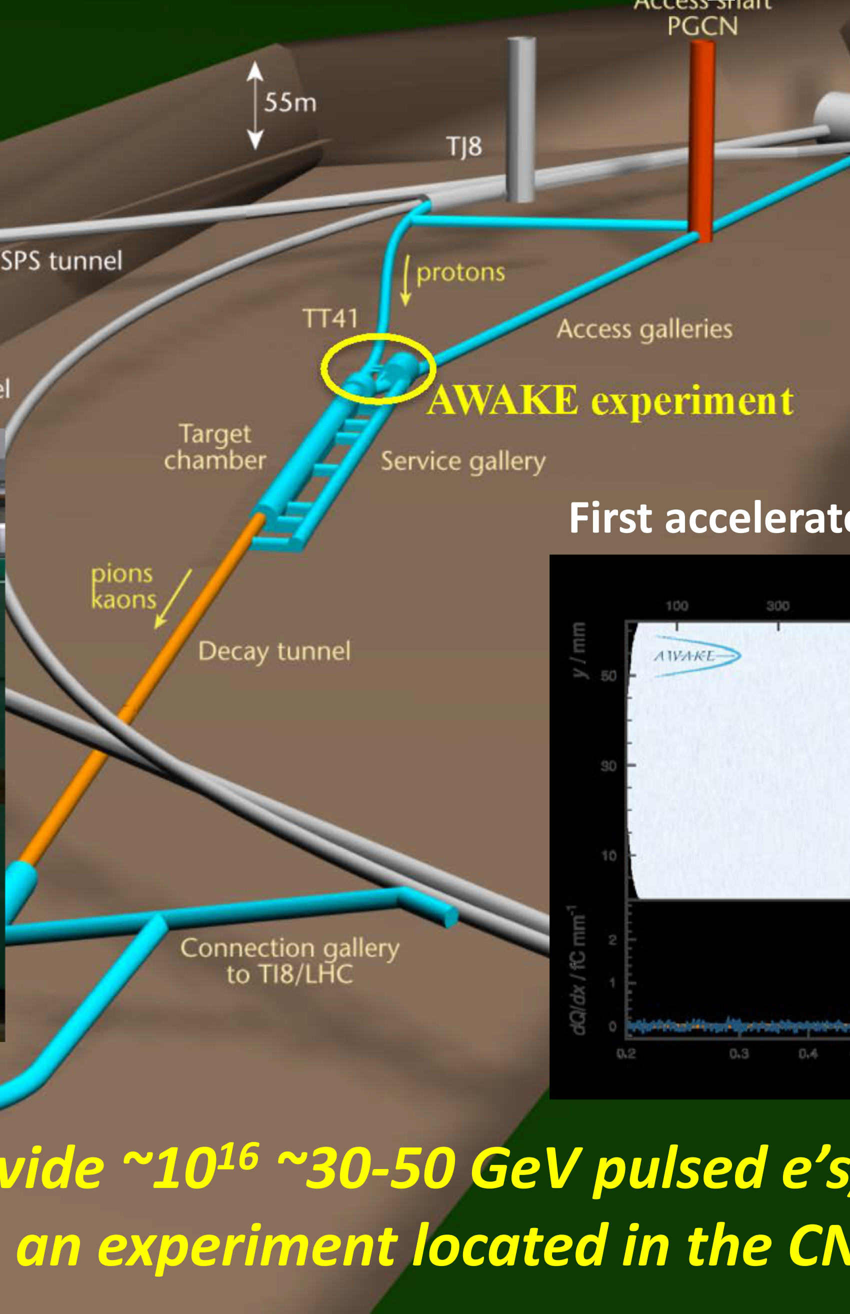
Also proposed at SLAC

EoI sent to SPSC in October 2018:
https://cds.cern.ch/record/2640784

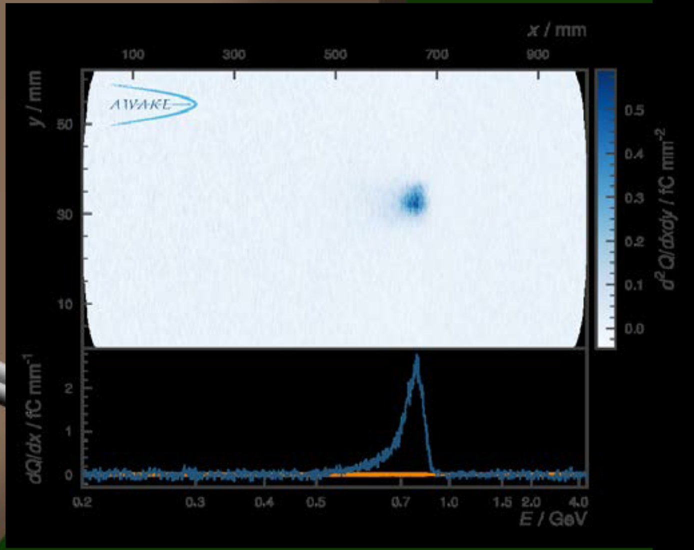
Electron-Dump at AWAKE

Beam Dump technique

R&D for electron acceleration with a plasma cell excited by SPS proton bunches

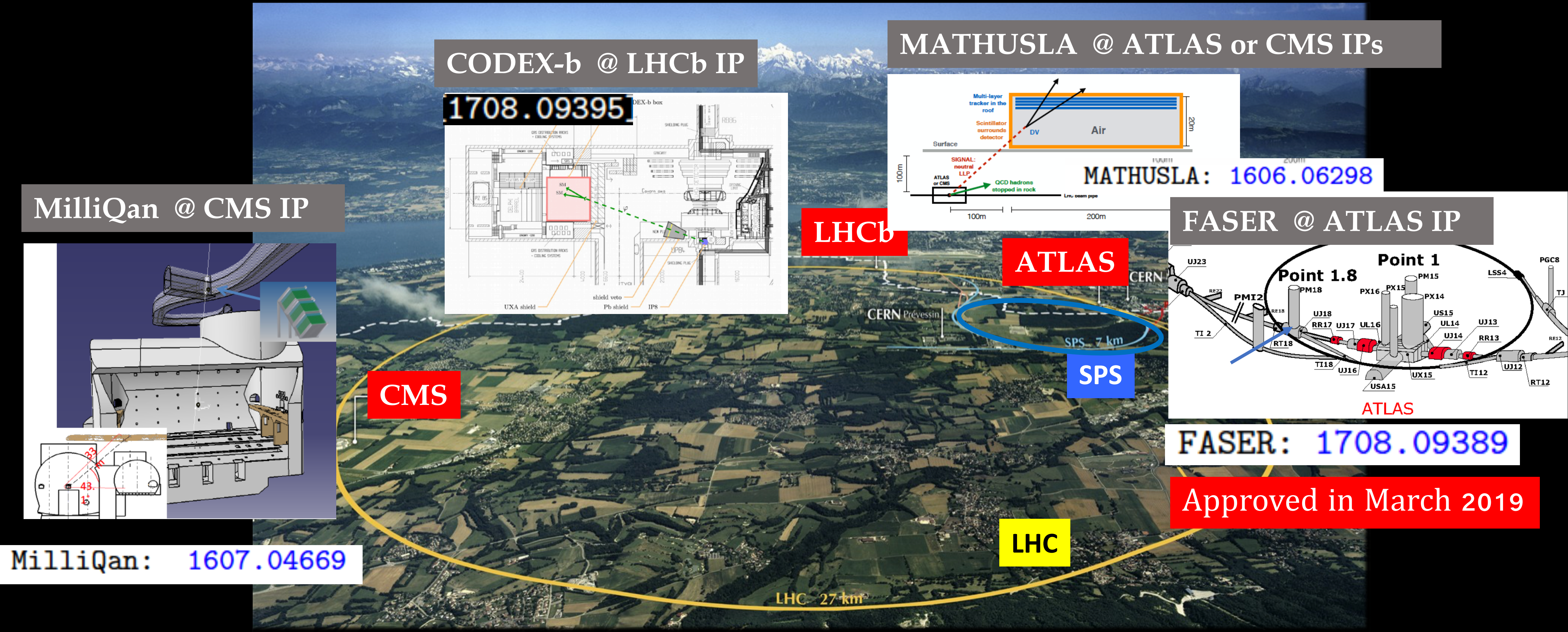


First accelerated e- seen in 2018!



Could provide ~10^{16} ~30-50 GeV pulsed e's/year in the post-LS3 era to an experiment located in the CNGS decay tunnel

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



Physics Reach

(or how to compare the sensitivities of different experiments using the same benchmark models)

Physics Reach

(or how to compare the sensitivities of different experiments using the same benchmark models)

Four Generic Benchmark Cases

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:

PBC report, arXiv:1901.09966

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	$y_N LHN$

This is the set of the simplest fields and renormalizable (apart axion) interactions that can be added to the SM

Large consensus in the community to use these portals as generic benchmark cases to compare sensitivities
This is the bulk of the PBC BSM Physics programme.

Vector portal
(Dark Photons)

$$-\frac{\varepsilon}{2\cos\theta_W}F'_{\mu\nu}B^{\mu\nu}$$

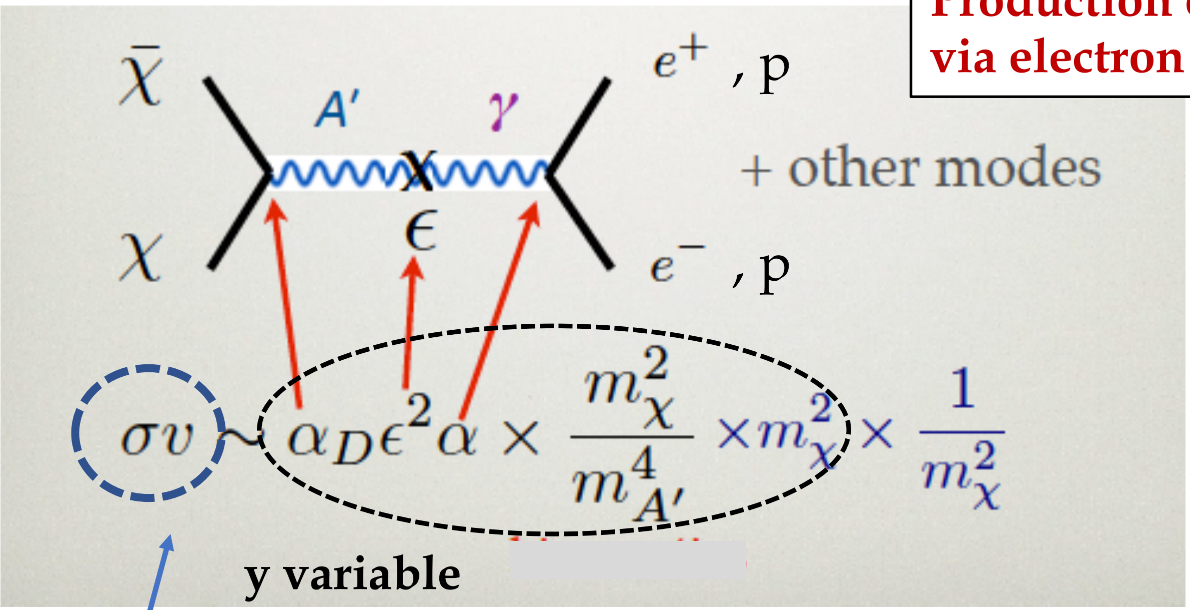
Dark Photon coupled to Light Dark Matter: connection with DM direct detection and cosmological bounds

Model where minimally coupled viable WIMP dark matter model can be constructed. The parameter space for this model is $\{m_{A'}, \epsilon, m_\chi, \alpha_D\}$. Vector mediator survives CMB constraints. Light vector mediator could also explain the positron excess observed by PAMELA, AMS…

Production of DM at accelerators via electron or proton bremsstrahlung

$$A' \to \chi\chi$$

Direct DM scattering with e/protons: Direct Detection experiments



Courtesy of P. Schuster

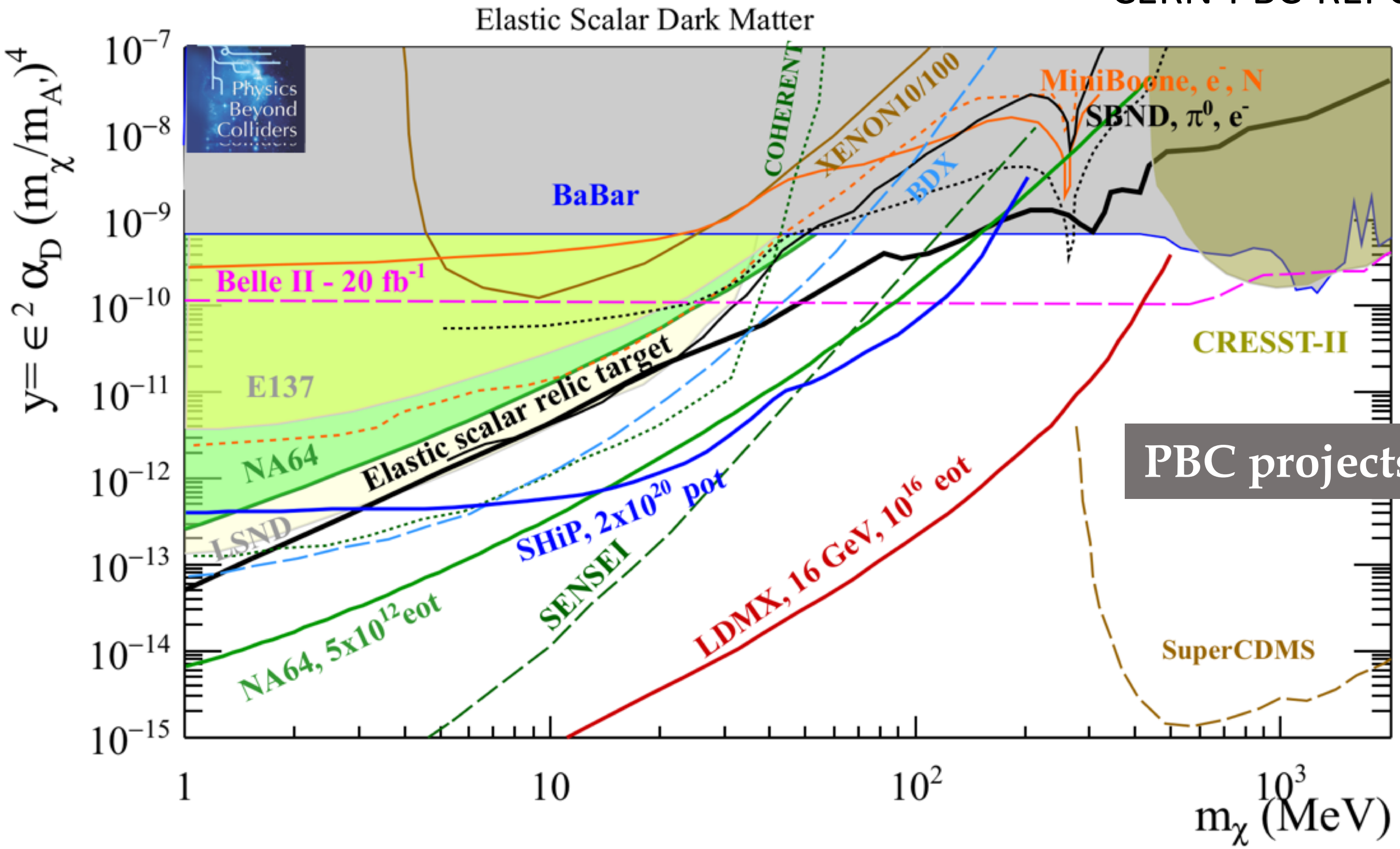
$$\Omega_{DM} h^2 \sim \frac{10^9 \text{ GeV}^{-1}}{M_{pl}} \frac{1}{\langle \sigma v \rangle}$$

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

Dark Photon coupled to Light Dark Matter

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: SHiP, LDMX, NA64++

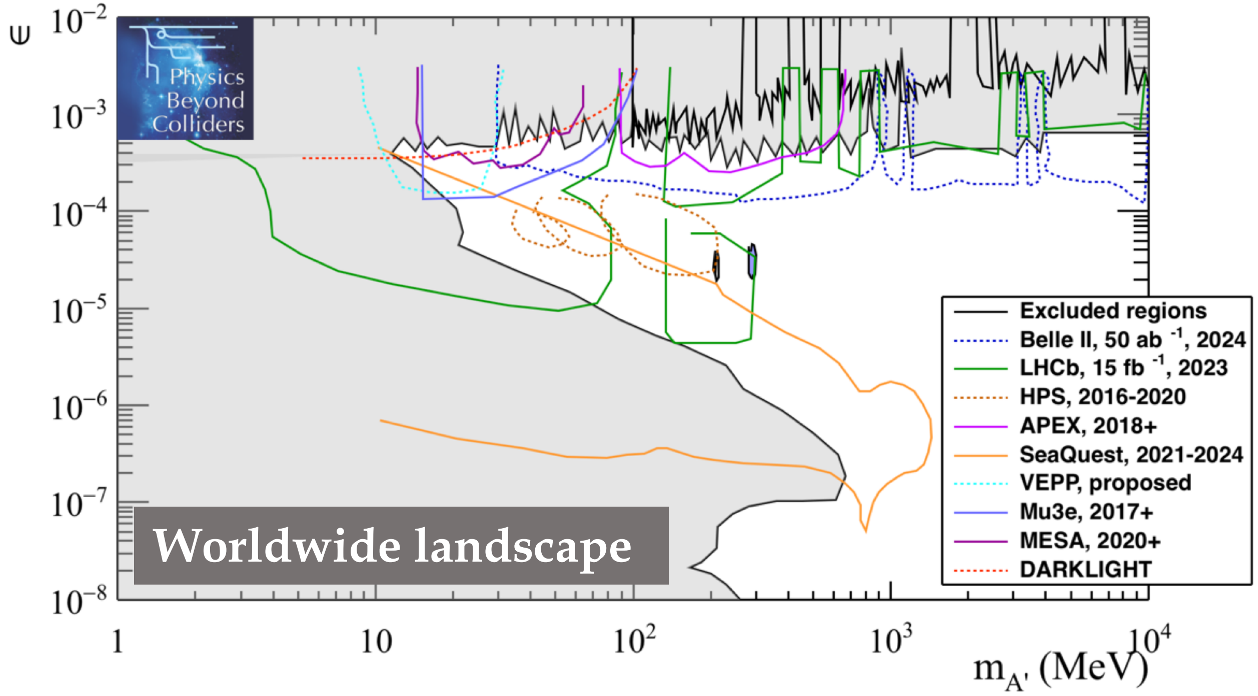
Nice complementarity between accelerator-based proposals, colliders and Light DM direct detection experiments.

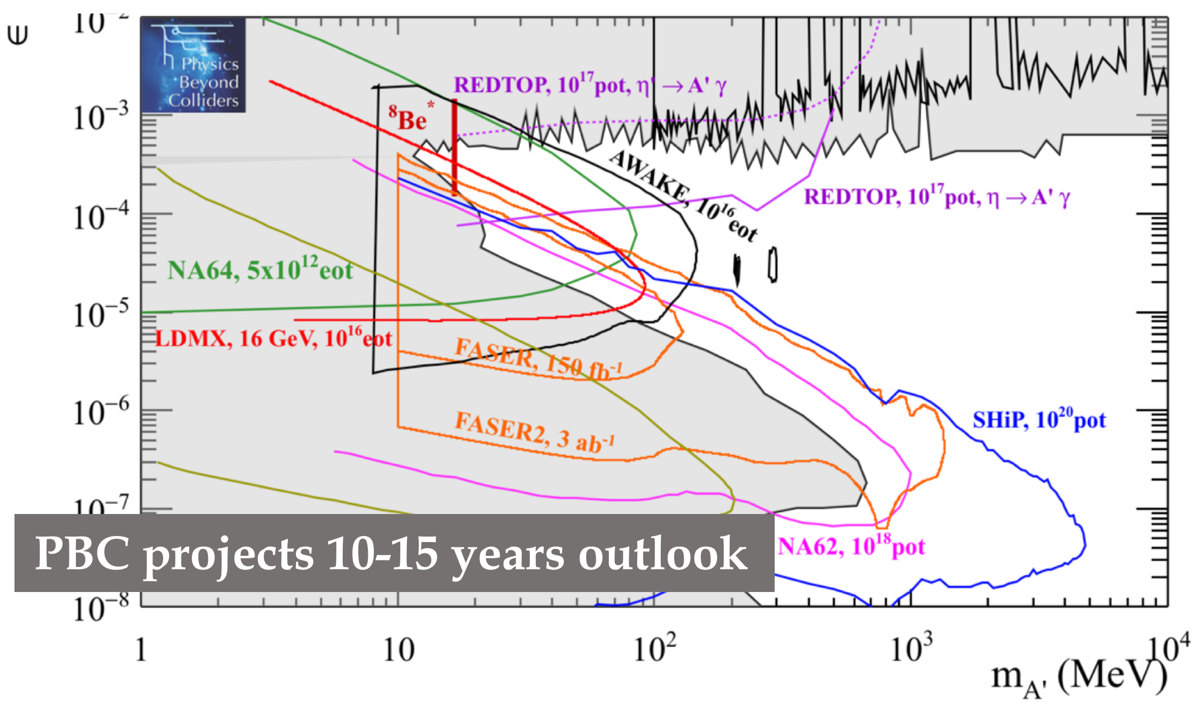
Dark Photon coupled to SM particles

The SM is augmented by a single new state A'. DM is assumed to be either heavy or contained in a different sector. Clearly a mixed case is possible with DP decaying to DM and visible final states: In that cases the rates to visible final states will depend on the assumption on alphaD. For simplicity here we assume alphaD=0.

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

CERN-PBC-REPORT-2018-007





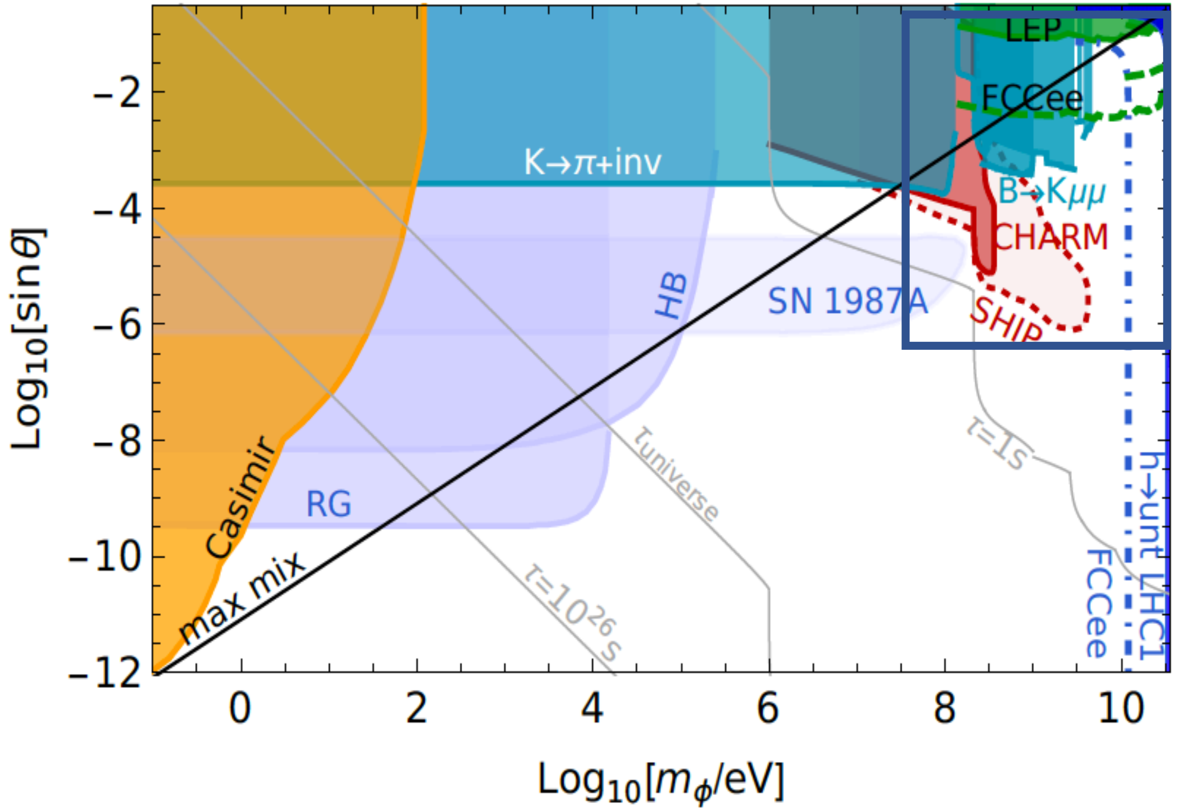
Nice complementarity/competition
with experiments in Japan, FNAL, JLAB, Mainz, PSI…..

Scalar portal
(Dark Scalar/relaxion)

$$(\mu S + \lambda S^2)H^\dagger H$$

PBC target: "heavy" relaxion/scalar-portal

Light feeble goldstone boson, may stabilize the Higgs mass against radiative corrections (relaxion)
light mediators between SM and LDM, connected to EW baryogenesis, etc.



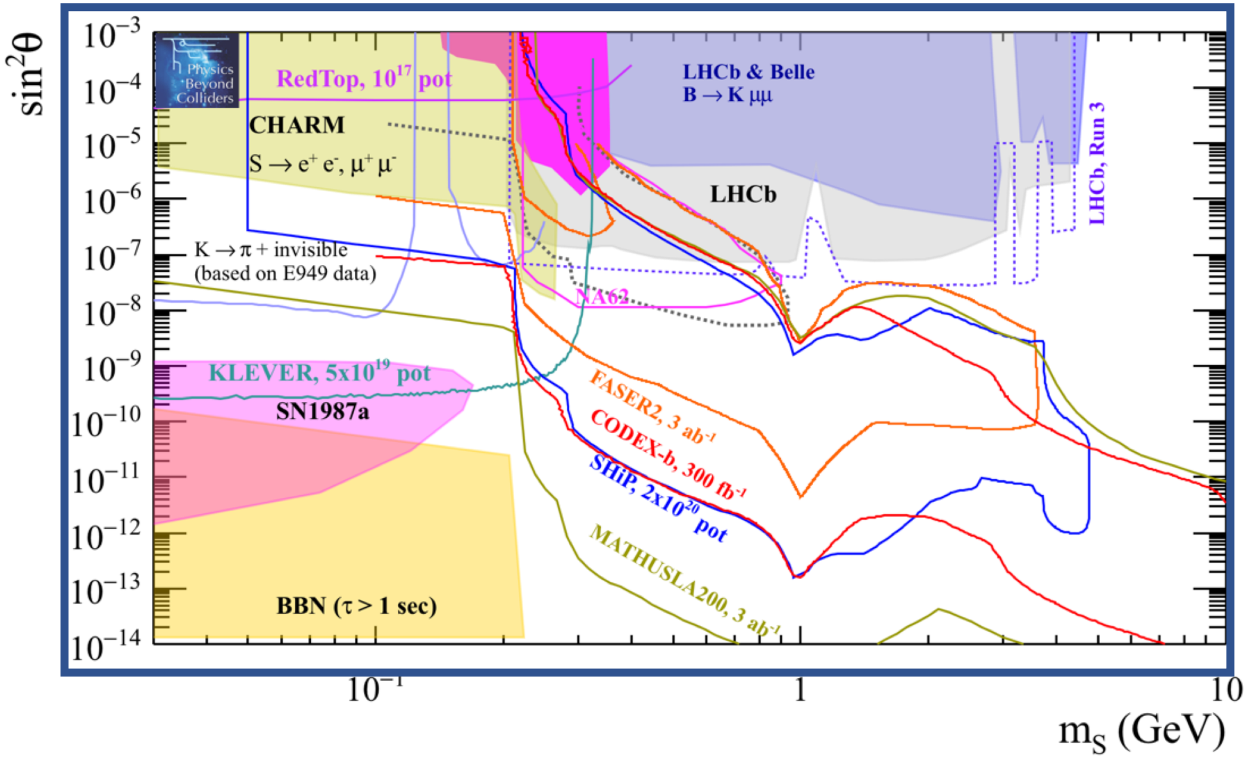
MeV-GeV range can be explored at CERN

PBC target: "heavy" relaxion/scalar-portal

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.

PBC report, 1901.09966

BR(H-> S S) = 1%, compatible with the Higgs invisible width (current and future, HL-LHC)



MeV-tens GeV range:

FASER, SHiP, CODEX-b, MATHUSLA, NA62++, REDTOP

Nice complementarity with astrophysical data and flavor results

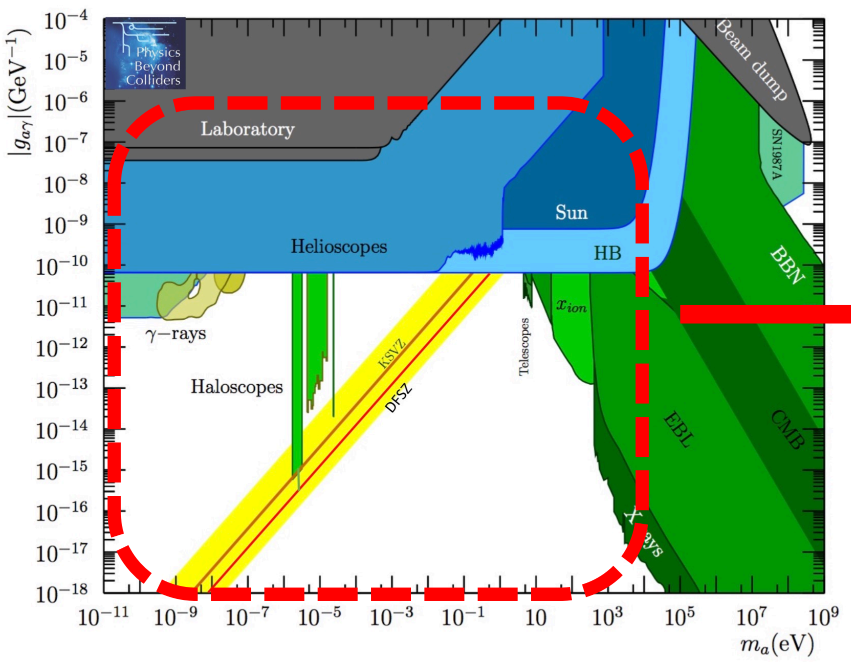
Axions/ALPs with photon couplings

$$\frac{a}{f_a} \tilde{F}_{\mu\nu} F^{\mu\nu}$$

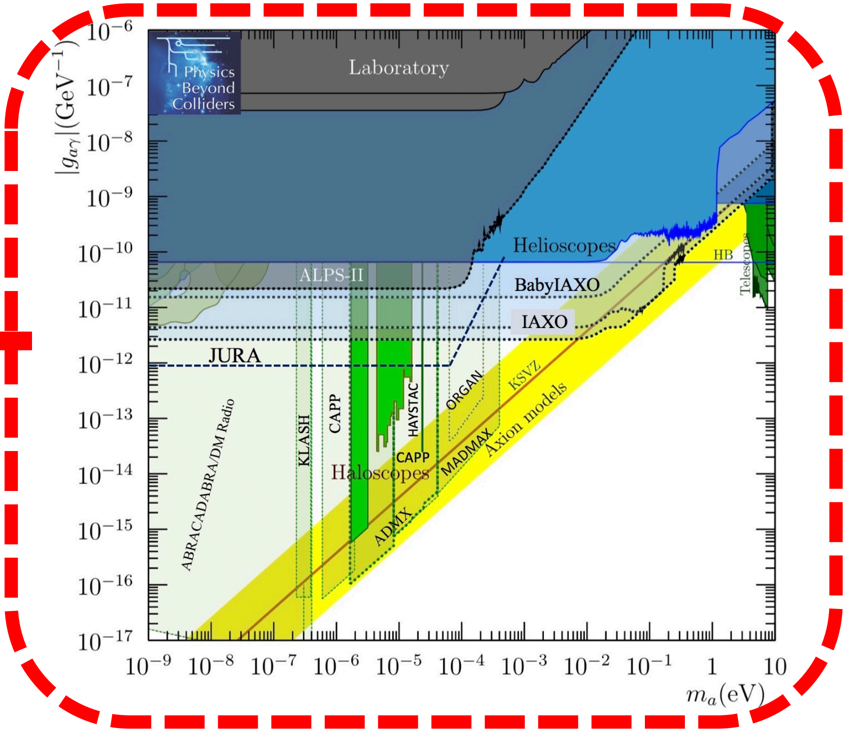
Axions and ALPs with photon coupling

Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range.

1901.09966



zoom in the sub-eV range



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

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

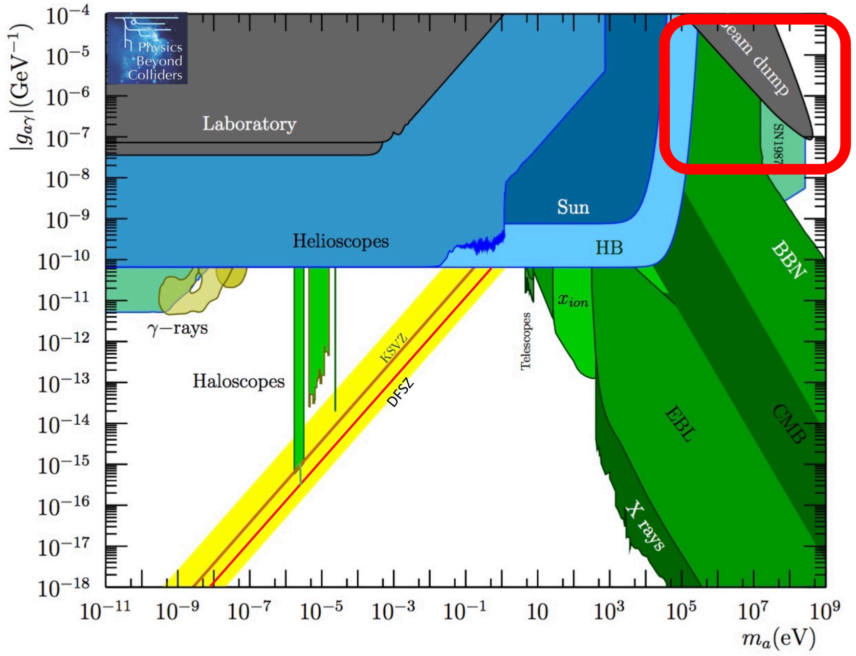
Extremely lively field in the sub-eV range (many projects ongoing)

Axions and ALPs with photon coupling

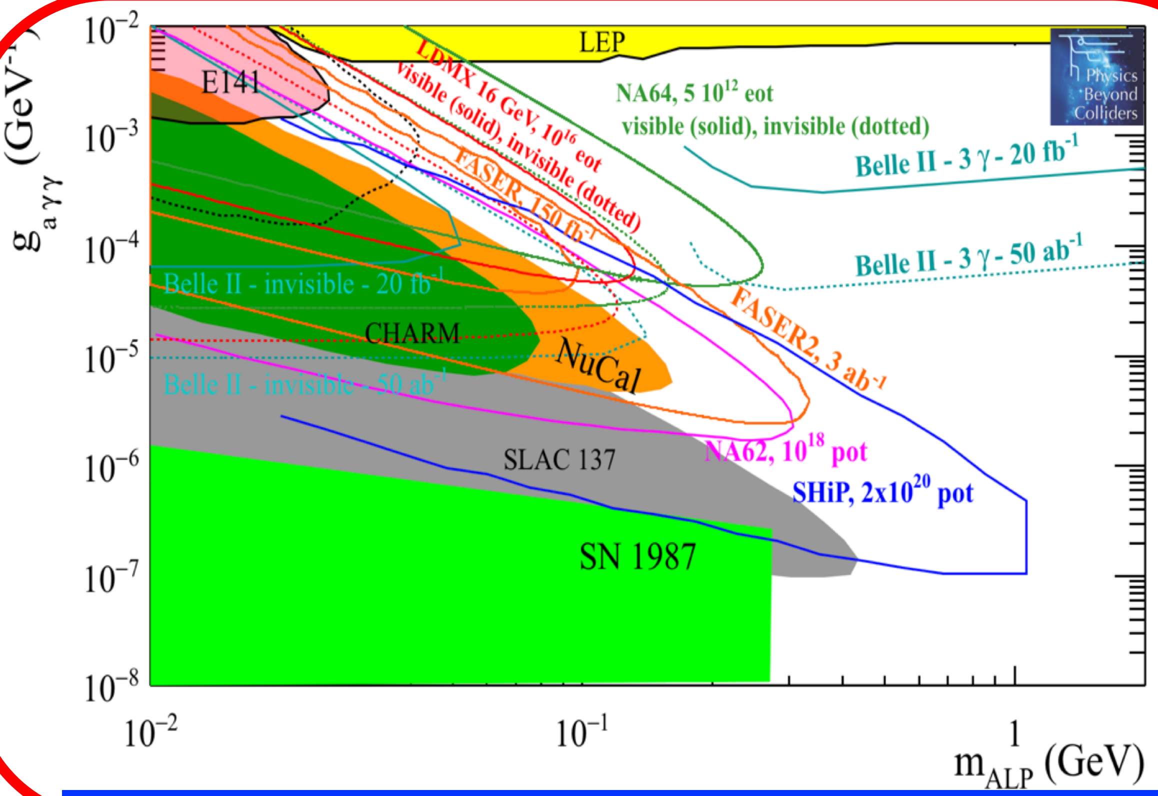
Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range

Need of a systematic investigation in the MeV-GeV range.

1901.09966



zoom in the MeV-GeV range



FASER, MATHUSLA, LDMX, NA62++, SHiP, NA64++.....

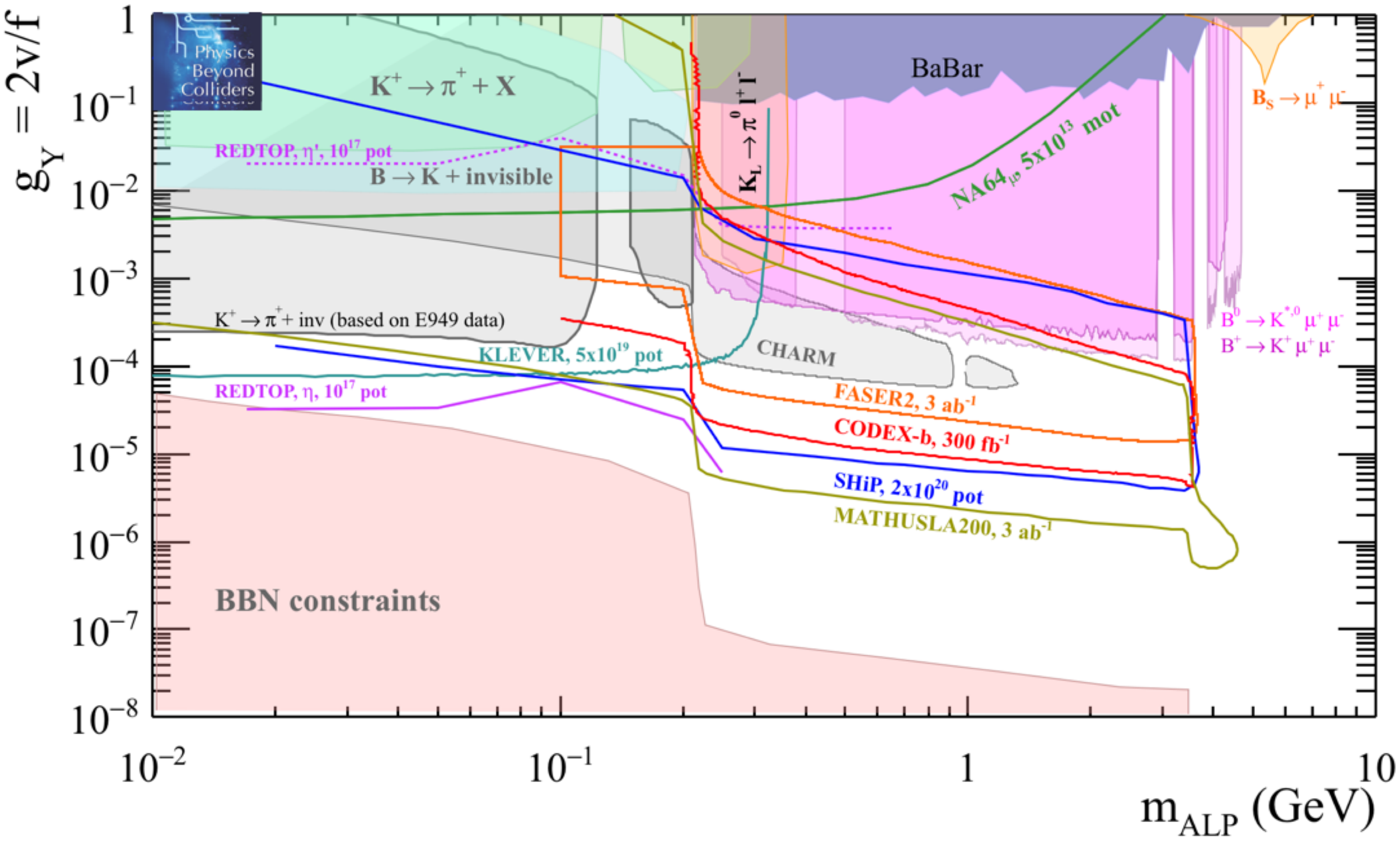
Nice complementarity of accelerator-based experiment
with experiments in the sub-eV range and cosmological bounds

Axions/ALPs with fermion couplings

$$\frac{\delta_\mu a}{f_a} \overline{\psi} \gamma^\mu \gamma^5 \psi$$

Accelerator-based experiments' reach: MeV-GeV range

PBC report, 1901.09966



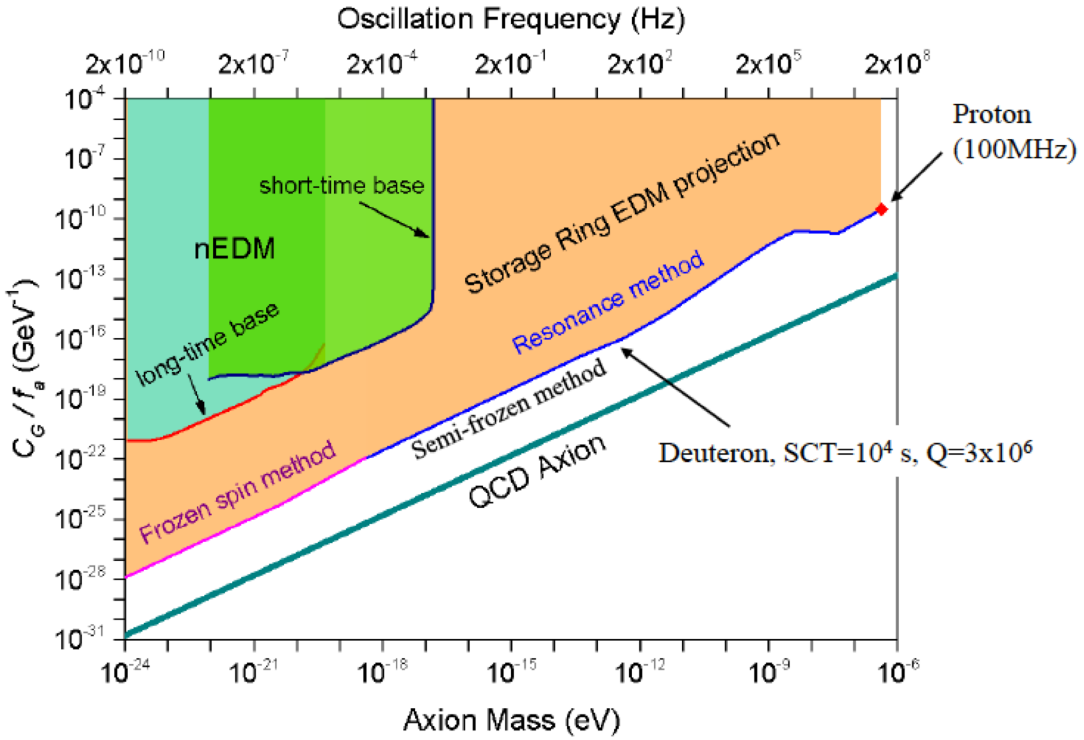
FASER, MATHUSLA, Codex-b, LHCb…

Axions/ALPs with gluon couplings

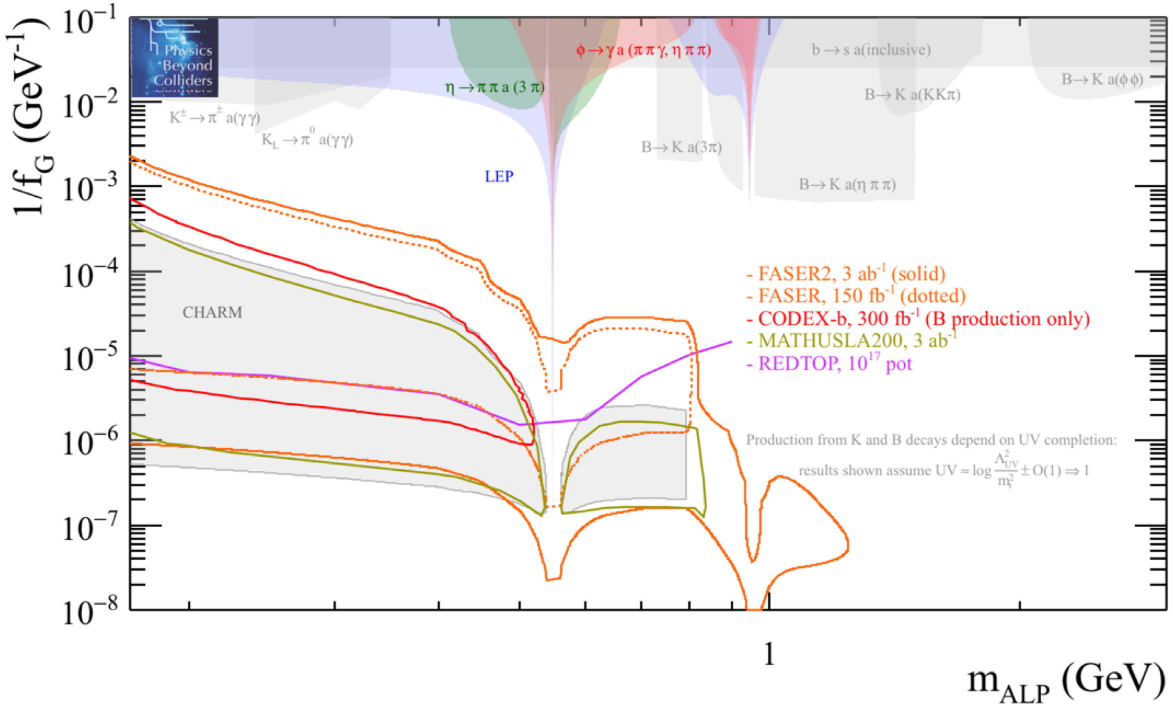
$$\frac{a}{f_a} \; \tilde{G}_{i,\mu\nu} G^{i,\mu\nu}$$

Axion portal - gluon couplings

Proton EDM: <10^{-6} eV range



Accelerator-based experiments' reach: MeV-GeV range



FASER, CODEX-b, MATHUSLA,…

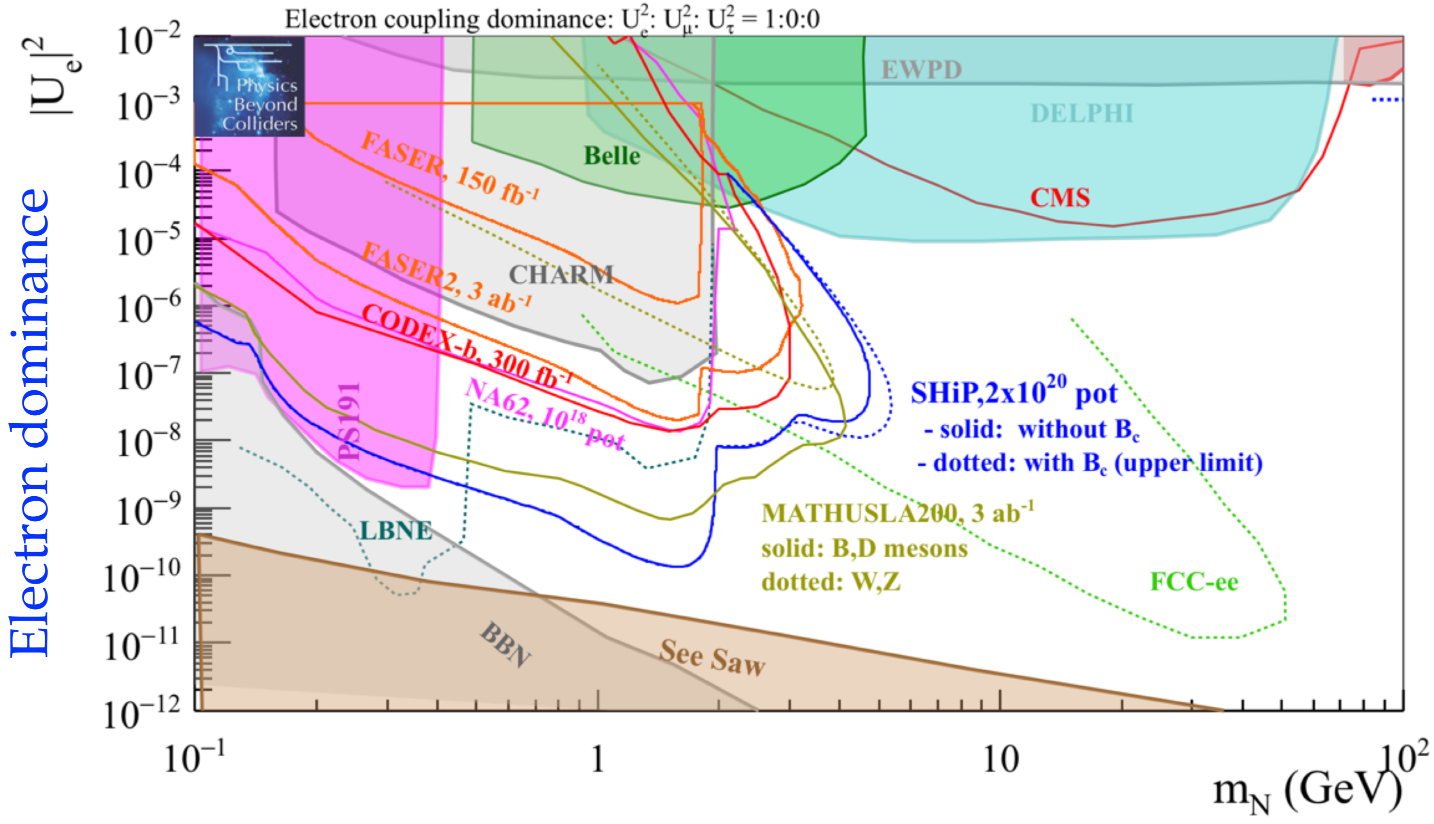
Fermion portal
(sterile neutrinos)

$$y_N \, LHN$$

Sterile neutrinos below the EW scale

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, 1901.09966



MATHUSLA, FASER, CODEX, and beam-dump exps

Physics Beyond Colliders Projects (BSM wg)

Since the TeV scale is very well explored at the LHC, focus on the sub-eV, MeV-GeV and multi-TeV scales:

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 LDM, HNLs, lepto-phobic DM, ..	BDF, SPS	400 GeV p	$2 \cdot 10^{20}$/5 years
NA62^{++}	ALPs, Dark Photons, Dark Scalars, HNLs	K12, SPS	400 GeV p	up to $3 \cdot 10^{18}$/year
NA64^{++}	ALPs, Dark Photons, Dark Scalars, LDM	H4, SPS	100 GeV e^-	$5 \cdot 10^{12}$ eot/year
	$+ L_\mu - L_\tau$	M2, SPS	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
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, Dark Photon, ALPs, HNLs	ATLAS or CMS IP	14 TeV p	3000 fb^{-1}
FASER	Dark Photon, Dark Scalar, ALPs, HNLs, $B - L$ gauge bosons	ATLAS IP	14 TeV p	3000 fb^{-1}
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}
>> 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

arXiv: 1901.09966

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

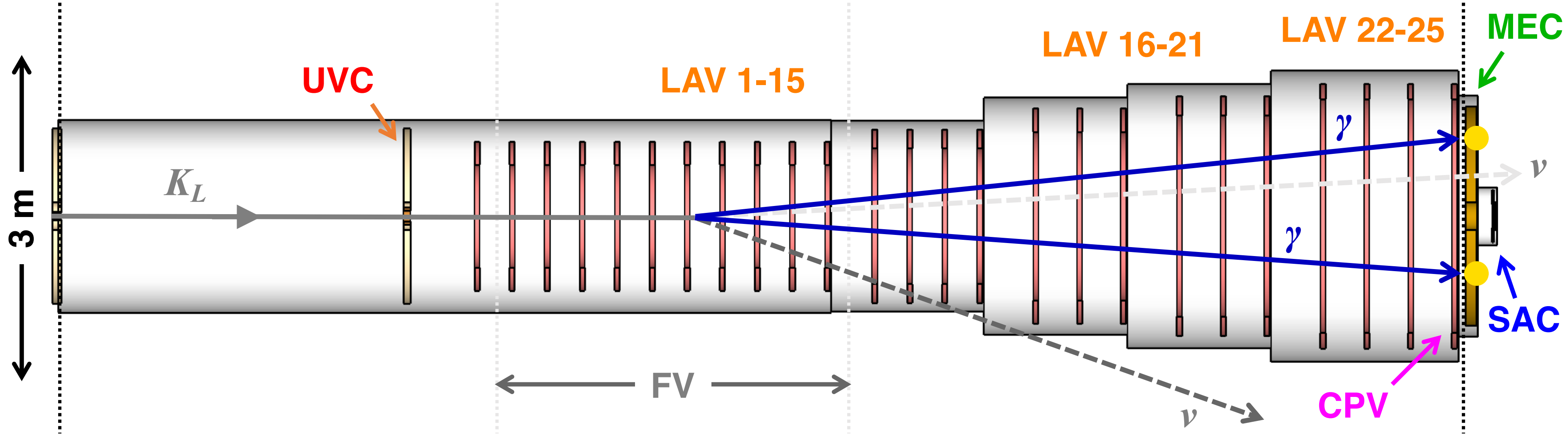
A multi-scale approach.

Physics reach in the multi-TeV scale via extremely rare/forbidden processes: KLEVER and TauFV projects

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

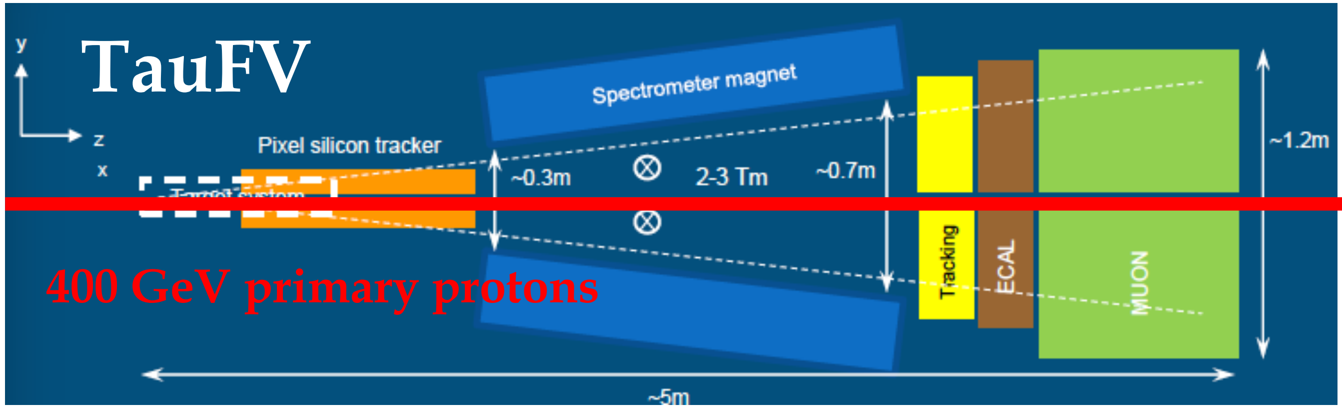
Competition:

KOTO (JPARC) expects to reach SM sensitivity in 2021

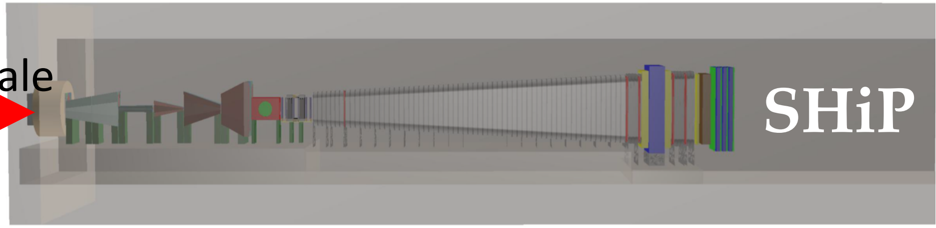
Strong intention to integrate o(100) events with a major upgrade of line and detector but no official proposal yet.

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.



not to scale



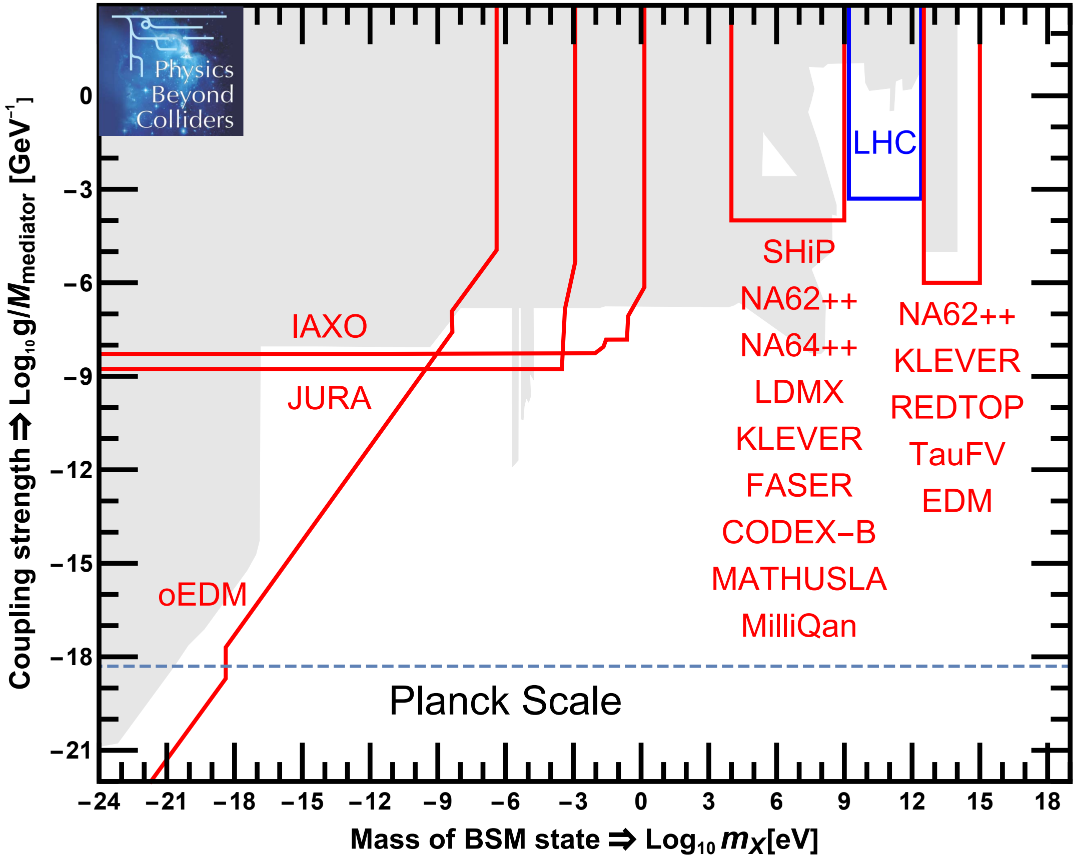
Profit of the higher signal yield than at any other facility:

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

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

PBC-BSM target: Axion and Axion-Like Particles

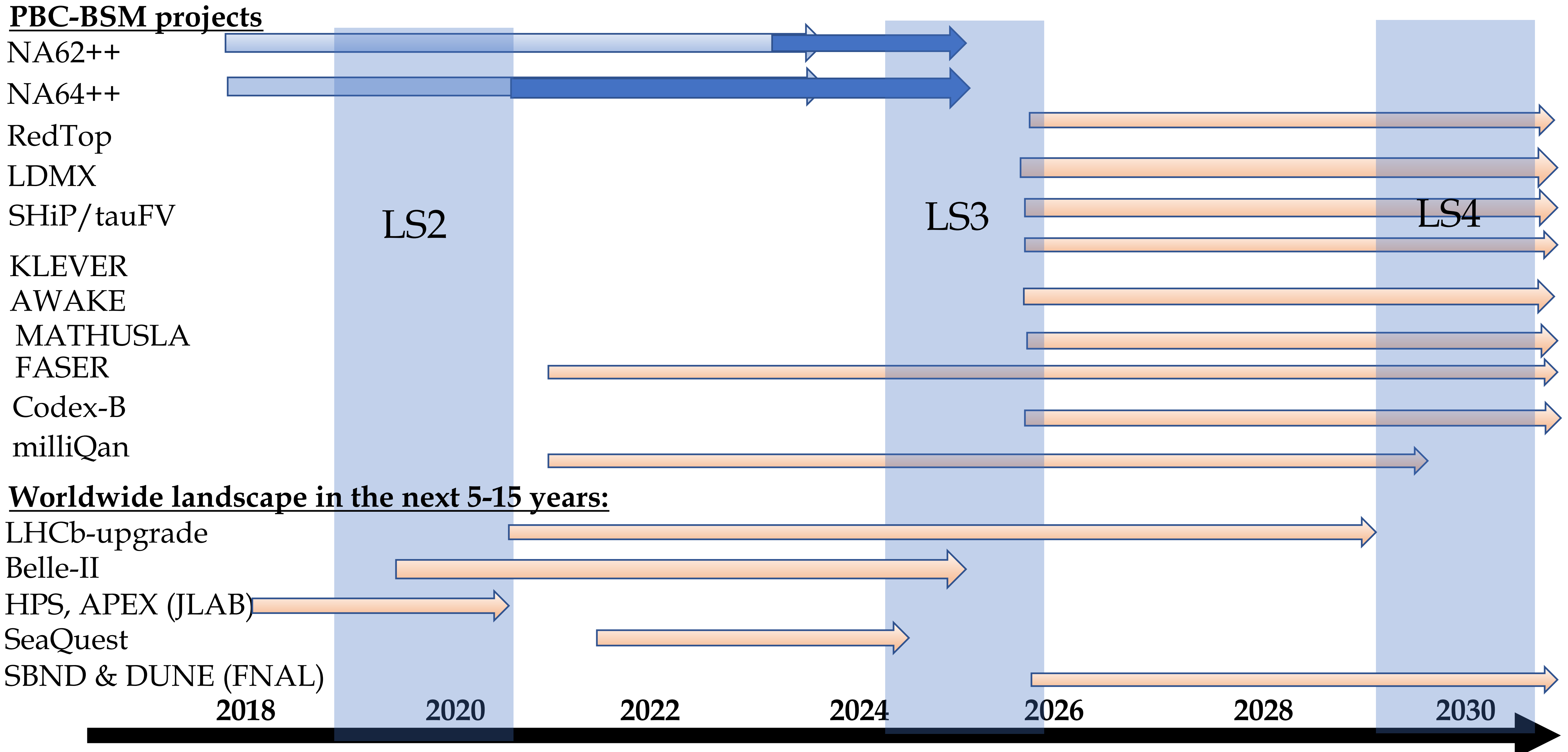
Schematic Physics Reach of PBC projects for axion/ALPs coupled to photons and gluons, compared to the LHC.



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

Timescale of accelerator-based PBC projects

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



European Strategy Update

Granada Symposium for the European Strategy Update
13-16 May 2019

Feebly interacting long-lived particles very popular topic across the ESPP inputs. Lively discussions expected in Granada…..

Now we are going to repeat the exercise of the four portals to compare the sensitivities of experiments at the main future colliders. Plots in preparation.

- BSM at colliders:

160 - HE-LHC
152 - HL-LHC
151 – Heavy Ions
145 - CLIC
135 - FCC-int
120 – Muon collider
101 - FCC-ee
94 - FASER
77 - ILC
75 - MATHUSLA
29 - CEPC

- Dark Matter and Dark Sector:

1 - Sterile Neutrinos at CERN (NA62/SHiP)
9 - NA64
12 – SHiP
36 - Dark Sector Physics with primary electron beam (eSPS)
42 - Physics Beyond Colliders
50 - Particle Physics with AWAKE

- Flavor:

11 – Belle-II experiment at super KEK-B
28 – REDTOP
153 - KLEVER

Conclusions and Outlook

- The target of the PBC-BSM activity is a broad, rich and compelling physics program which addresses the open questions of particle physics in a complementary way to the LHC, HL-LHC, FCC , CEPC, ILC, 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 portals framework will be applied to the big colliders physics reach. Results for Granada.

- 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.

All this will be discussed in the upcoming ESPP Granada Symposium in May

CERN

Physics Beyond Colliders

Thank you for your attention