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

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(+ experiments representatives)

Benasque, Spain, 9th April 2019
Experimental facts

With found the Higgs with a mass $\sim 125$ GeV....
Experimental facts

With found the Higgs with a mass $\sim 125$ GeV....
.....and nothing else
Experimental facts

With found the Higgs with a mass $\sim 125$ GeV….
…..and nothing else:
- no new particles
- no (unambiguous) hint of NP in flavor
- no WIMP-like DM candidate
Experimental facts

With found the Higgs with a mass ~ 125 GeV....
.....and nothing else:
- no new particles
- no (unambiguous) hint of NP in flavor
- no WIMP-like DM candidate

“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 $M_{\text{Planck}} = 1.22 \times 10^{19}$ GeV as the highest energy to worry about.
...and self-consistent up to the Planck scale!

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

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:
   → in the Standard Model neutrinos are massless and do not oscillate.

2) Evidence for Dark Matter
   → Standard Model does not have particle candidate for DM.

3) No antimatter in the Universe in amounts comparable with matter:
   → 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 (?):
   → though can be “explained” by a cosmological constant.

Where to look for New Physics?
"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:
- 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

Physics Working Groups

- BSM physics working group
- QCD physics working group
- FASER study
- eSPS study
- Proton production study
- NuSTORM study
- AWAKE++ study
- Gamma Factory study

Exploratory Studies

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

< 10 keV
DM too hot, spoils structure formation

1 MeV

1 GeV

M_Z

10 TeV

> 100 TeV
DM overproduced

Increasing interest also in the DM direct detection community (lively and growing field)
PBC target: “heavy” relaxion/scalar-portal

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

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.

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

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

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

Standard choice: GUT see-saw

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

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

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

A multi-scale approach.
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

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

Possible site: 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.

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 $\theta_{QCD}$

Expected sensitivity
For the CP-EDM project

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 $\rightarrow$ search for axions.

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

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Main Physics Cases</th>
<th>Beam Line</th>
<th>Beam Type</th>
<th>Beam Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAXO</td>
<td>axions/ALPs (photon coupling)</td>
<td>--</td>
<td>axions from sun</td>
<td>--</td>
</tr>
<tr>
<td>JUSA</td>
<td>axions/ALPs (photon coupling)</td>
<td>laboratory</td>
<td>LSW</td>
<td>--</td>
</tr>
<tr>
<td>CPEDM</td>
<td>$p, d$ eEDMs</td>
<td>EDM ring</td>
<td>p, d</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>axions/ALPs (gluon coupling)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

### MeV-GeV mass range

- **Proposals**:
  - SHF: ALPs, Dark Photons, Dark Scalars, LDM, HNLs, leptophobic DM, ...
  - NA62++: ALPs, Dark Photons, Dark Scalars, HNLs
  - NA64++: ALPs, Dark Photons, Dark Scalars, LDM + $L_B - L_D$
  - LDMX: Dark Photons, LDM, ALPs, ...
  - AWAKE/NA64: Dark Photons, eSPS
  - RedTop: Dark Photons, Dark Scalar, ALPs, CERN PS
  - MATHUSLA90: Weak-scale LLPs, Dark Scalar, Dark Photon, ALPs, HNLs
  - MATHUSLA90: Dark Photons, Dark Scalar, ALPs, HNLs, H-$L$ gauge bosons, milli charge
  - CODEX: Dark Scalar, HNLs, ALPs, ...
  - CODEX-b: Dark Scalar, HNLs, ALPs, ...

### TeV mass range

- **Proposals**:
  - KLEVER: $K_L \to \pi^0\pi^0$
  - TauT: LFV $\tau$ decays
  - CPEDM: $p, d$ eEDMs
  - ALPs (gluon coupling)
  - LHC-FT: charmed hadrons MDMs, EDMs

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

Active dump

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

[Diagram showing missing momentum technique]

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 $3 \times 10^{18}$ pot/year (now)
up to $10^{19}$ pot/year (upgrade)

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

**SHiP, TauFV @ BDF**
400 GeV p
up to $4 \times 10^{19}$ 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/

Currently running in kaon mode
Possibility to run in dump-mode in 2023
NA62 in “dump” mode (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 ($2 \times 10.7 \lambda_I$).

→ this operation is easy, quick (15 minutes) and fully reversible.

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

NA62 dump
(3.2 m of Cu + Fe)

25
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.


Active Dump technique
NA64++: electrons, muons and hadrons

Proposal to extend the physics programme after LS2:

NA64++ (electrons): extension beyond 2021 to accumulate up to $5 \times 10^{12}$ 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 $\pi(K) p \rightarrow M^0 n + E_{\text{miss}}$

Eg: search for a $Z_\mu$ 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 $4 \times 10^{19}$ pot/year (the same number sent to the CNGS)

New line branching off in TDC2.

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

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;

Missing momentum technique

Also proposed at SLAC

EoI sent to SPSC in October 2018: https://cds.cern.ch/record/2640784
Electron-Dump at AWAKE

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

First accelerated e- seen in 2018!

Could provide \( \sim 10^{16} \) ~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

CODEX-b @ LHCb IP

MATHUSLA @ ATLAS or CMS IPs

MilliQan @ CMS IP

LHCb

ATLAS

SPS

CMS

LHC

FASER @ ATLAS IP

Beam Dump Technique

MilliQan: 1607.04689

FASER: 1708.09389

Approved in March 2019
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:

<table>
<thead>
<tr>
<th>Portal</th>
<th>Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Photon, $A_\mu$</td>
<td>$-\frac{\epsilon}{2\cos\theta_W} F'_\mu\nu B^{\mu\nu}$</td>
</tr>
<tr>
<td>Dark Higgs, $S$</td>
<td>$(\mu S + \lambda S^2) H^\dagger H$</td>
</tr>
<tr>
<td>Axion, $a$</td>
<td>$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu} \tilde{G}<em>i^{\mu\nu}$, $\frac{\delta</em>{\mu a}}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$</td>
</tr>
<tr>
<td>Sterile Neutrino, $N$</td>
<td>$y_N L H N$</td>
</tr>
</tbody>
</table>

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…

Direct DM scattering with e/protons: Direct Detection experiments

Production of DM at accelerators via electron or proton bremsstrahlung

Direct DM annihilation (main process to get the thermal relic abundance)
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\( (\chi) \)
\( \alpha(D) = 0.1 \)

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 $\alpha_D$. For simplicity here we assume $\alpha_D=0$.

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

Worldwide landscape

PBC projects 10-15 years outlook

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

(Dark Scalar/relaxion)

$(\mu S + \lambda S^2)H^\dagger H$
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
The Higgs portal couples the dark sector to the Higgs boson via the bilinear $H^\dagger H$ operator of the SM. The minimal scalar portal model operates with one extra singlet field $S$ and two types of couplings, $\mu$ and $\lambda$.

$\text{BR}(H \rightarrow SS) = 1\%$, 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

\[ \frac{\alpha}{f_a} \tilde{F}_{\mu \nu} F^{\mu \nu} \]
Search for axions/ALPs: extremely lively and established field, mostly in the sub-eV mass range.

1901.09966

Axions and ALPs with photon coupling

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)
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

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

zoom in the MeV-GeV range

Nice complementarity of accelerator-based experiment with experiments in the sub-eV range and cosmological bounds
Axions/ALPs with fermion couplings

$$\frac{\delta \mu}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$$
Accelerator-based experiments’ reach: MeV-GeV range

PBC report, 1901.09966

FASER, MATHUSLA, Codex-b, LHCb…
Axions/ALPs with gluon couplings

\[ \frac{\alpha}{f_a} \tilde{G}_{i,\mu\nu} G^{i,\mu\nu} \]
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.
Since the TeV scale is very well explored at the LHC, focus on the sub-eV, MeV-GeV and multi-TeV scales:

### A multi-scale approach.

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

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<table>
<thead>
<tr>
<th>Propose</th>
<th>Main Physics Cases</th>
<th>Beam Line</th>
<th>Beam Type</th>
<th>Beam Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>sub-eV mass range:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAXO</td>
<td>axions/ALPs (photon coupling)</td>
<td></td>
<td>LSW</td>
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<tr>
<td>JURA</td>
<td>axions/ALPs (photon coupling)</td>
<td>laboratory</td>
<td></td>
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<td>CPEDM</td>
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<td>LHC-FT</td>
<td>axions/ALPs (gluon coupling)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MeV-GeV mass range:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHIP</td>
<td>ALPs, Dark Photons, Dark Scalars</td>
<td>EDF, SPS</td>
<td>400 GeV p</td>
<td>2 \cdot 10^{23}/5 years</td>
</tr>
<tr>
<td>NA61++</td>
<td>ALPs, Dark Photons, Dark Scalars, HNLs</td>
<td>K12, SPS</td>
<td>400 GeV p</td>
<td>up to 3 \cdot 10^{18}/year</td>
</tr>
<tr>
<td>NA64++</td>
<td>ALPs, Dark Photons, Dark Scalars, LDM</td>
<td>H4, SPS</td>
<td>100 GeV e^-</td>
<td>5 \cdot 10^{12} e^+/year</td>
</tr>
<tr>
<td>LDMX</td>
<td>ALPs, Dark Photons, LDM</td>
<td>M2, SPS</td>
<td>160 GeV μμ</td>
<td>10^{12} – 10^{13} mc/year</td>
</tr>
<tr>
<td>AWAKE/NA64</td>
<td>Dark Photon, LDM, ALPs</td>
<td>eSPS</td>
<td>8 (SLAC)-16 (sPS) GeV e^-</td>
<td>10^{18} – 10^{19} e^+/year</td>
</tr>
<tr>
<td>RedTop</td>
<td>Dark Photon, Dark scalar, ALPs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MATTHUSLA200</td>
<td>Weak-scale LLPs, Dark Scalar, Dark Photon, ALPs, HNLs</td>
<td>ATLAS or CMS IP</td>
<td>14 TeV p</td>
<td>3000 fb^-1</td>
</tr>
<tr>
<td>FASER</td>
<td>Dark Photons, Scalar, ALPs, HNLs, H – L gauge bosons</td>
<td>CMS IP</td>
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<td>300-3000 fb^-1</td>
</tr>
<tr>
<td>MilliQan</td>
<td>Dark Scalar, HNLs, ALPs</td>
<td>LHCb IP</td>
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#### >> TeV mass range:

<table>
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<tbody>
<tr>
<td>KLEVER</td>
<td>K_L → τ^+τ^-</td>
<td>P42/K12</td>
<td>400 GeV p</td>
<td>5 \cdot 10^{15} pot/5 years</td>
</tr>
<tr>
<td>Tau0V</td>
<td>LFV τ decays</td>
<td>BDF</td>
<td>400 GeV p</td>
<td>(\alpha(2%)) of the BDF proton yield</td>
</tr>
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<td>axions/ALPs (photon coupling)</td>
<td>EDM ring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHC-FT</td>
<td>charmed hadrons MDMs, EDMs</td>
<td>LHCb IP</td>
<td>7 TeV p</td>
<td></td>
</tr>
</tbody>
</table>
Physics reach in the multi-TeV scale via extremely rare/forbidden processes: KLEVER and TauFV projects
KLEVER @ K12: an experiment to measure $K_L \rightarrow \pi^0 \nu \nu$ branching fraction

$10^{19} \text{ pot/yr} \times 5 \text{ years} \rightarrow 2 \times 10^{13} \text{ ppp/16.8s} = 6\times \text{ increase relative to NA62}$

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

KLEVER target sensitivity:
5 years starting in Run 4
~ 60 SM $K_L \rightarrow \pi^0 \nu \nu$ 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.

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

\[ \tau \rightarrow \mu \mu \mu \text{ yield assuming a BR } \sim 10^{-9} \]

<table>
<thead>
<tr>
<th>Future experiment</th>
<th>Yield</th>
<th>Extrapolated from</th>
</tr>
</thead>
<tbody>
<tr>
<td>TauFV (4 \times 10^{18} \text{ PoT})</td>
<td>8000</td>
<td>Numbers on this slide</td>
</tr>
<tr>
<td>Belle II (50 \text{ ab}^{-1})</td>
<td>9</td>
<td>PLB 687 (2010) 139</td>
</tr>
<tr>
<td>LHCb Upgrade I (50 \text{ fb}^{-1})</td>
<td>140</td>
<td>JHEP 02 (2015) 121</td>
</tr>
<tr>
<td>LHCb Upgrade II (300 \text{ fb}^{-1})</td>
<td>840</td>
<td>ditto</td>
</tr>
</tbody>
</table>
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

PBC-BSM projects
- NA62++
- NA64++
- RedTop
- LDMX
- SHiP/tauFV
- KLEVER
- AWAKE
- MATHUSLA
- FASER
- Codex-B
- milliQan

Worldwide landscape in the next 5-15 years:
- LHCb-upgrade
- Belle-II
- HPS, APEX (JLAB)
- SeaQuest
- SBND & DUNE (FNAL)
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.
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.
Thank you for your attention