Light Dark Matter in the SHiP experiment

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- SHiP (Search for Hidden Particles) will be fixed target experiment exploiting 400 GeV proton beam from the CERN SPS.
  (The original motivation of the experiment was a search for $\mathcal{O}(1)$ GeV sterile neutrinos (HNL-s))
- The SHiP experiment will be equipped with a tau neutrino detector, which can be used to search for a LDM.

Light Dark Matter (LDM)

- Low mass: we need a mediator to ensure correct relic density
  (P. Fayet; Pospelov, Ritz and Voloshin '2008)
- Sensitivity of direct detection experiments is poor for low masses ($\simeq 1$ GeV)
- Reference model: vector mediator and scalar DM:

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu} + \frac{m_{A'}^2}{2}A'_\mu A'^\mu + |D_\mu\chi|^2 - m_\chi^2|\chi|^2$$

χ and A' are DM and mediator fields, $F_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu$, $D_\mu = \partial_\mu + ie'A'_\mu$,
e' is the $U'(1)$ coupling constant and ϵ is the parameter of kinematic mixing.
Four parameters: $m_{A'}$, m_χ, $\epsilon\, e$, $\alpha' \equiv e'^2/4\pi$
A': hidden, dark, secluded, para- photon

Production and detection @ fixed target experiments

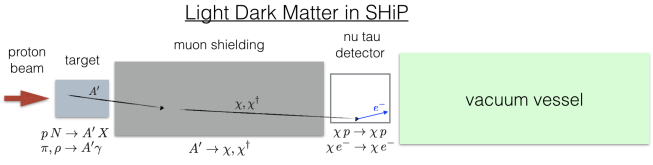
Two main production channels:

1. Direct production.
   In the case of the SHiP experiment it corresponds to hadron-level: $pp \to A' \to \chi^\dagger\chi$
2. Production in radiative meson decays: $\pi^0, \rho \to \gamma A'$, $A' \to \chi^\dagger\chi$

In the narrow width approximation (assuming that the hidden photon is sufficiently long-lived, $\Gamma(A') \ll m_{A'}$)

$$\sigma(pN \to A' \to \chi\bar{\chi}) = \sigma(pN \to A')\mathrm{Br}(A' \to \chi\bar{\chi})$$

SHiP



- 400 GeV proton beam from SPS.
- $2 \cdot 10^{20}$ POT in 5 years — **intensity frontier**.
- Molybdenum - Tungsten target. Goal: reduce the ν_μ background by stopping charged pions
- Active muon shielding $\sim$ 35 m of tungsten + sophisticated configuration of magnetic field. Idea: place detector close to target.
- ν_τ detector: OPERA-type bricks with a total mass of about 10 tonnes
- Decay volume: evacuated vessel

ship.web.cern.ch

Direct production of Dark Photon

Production in radiative meson decays:

$\pi^0 \to \gamma A'$, $A' \to \chi^\dagger\chi$

Proton-proton bremsstrahlung (in the WW approximation)

There are still some theoretical questions. Different approaches:

- Conservative: Gorbunov, Makarov, IT, Phys.Rev. D91 (2015) 3, 035027
- Optimistic: deNiverville, Chen, Pospelov and Ritz, Phys. Rev. D **95** (2017) no.3, 035006
  resonant vector meson mixing Faessler, Krivoruchenko and Martemyanov, Phys. Rev. C **82** (2010) 038201

Detection of DM

The elastic DM-electron scattering cross section

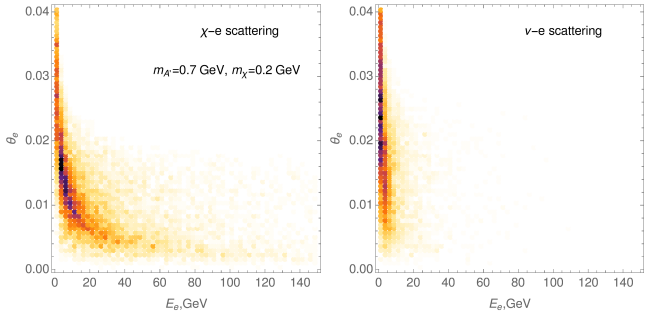
Background from elastic and deep inelastic neutrinos scatterings.

The elastic DM-nucleon cross section

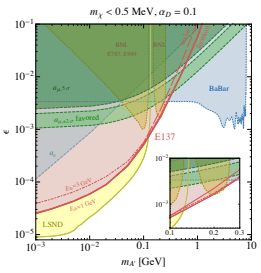
Deserves further investigation: Larger cross section, but the structure of the ν_τ target is complicated and it is not clear, what kind of signal can be observed.

Scattering of DM particles vs Elastic scattering of neutrino.

Toy Monte Carlo simulations of the SHiP setup. Homogeneous target.



Number of events as function of the electron scattering angle and the electron energy.



Batell, Essig and Surujon,
Phys. Rev. Lett. 113. 17, 171802)

Preliminary studies indicate that SHiP will be **competitive** with over fixed target facilities.