Constraints on the dark sector from the BEBC WA66 beam dump experiment

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Introduction

There is much focus on possible reach of future experiments on new dark states, e.g. SHiP.

Have we exhausted all the bounds from existing experiments on the coupling between the SM and any new states?

No - beam dump experiments may produce these dark states, whose detection signature is identical to neutral-current neutrino interactions.

Dedicated searches have been carried out for this SM process!

The models

Are there any dark fermionic states χ that couple to our photon?
The three most relevant operators are:

- $\epsilon e\bar{\chi}\gamma^{\mu}\chi A_{\mu}$ (millicharge ϵ);
- $\frac{1}{2}\mu\bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu}$ (magnetic dipole moment MDM μ);
- $\frac{i}{2}d\bar{\chi}\sigma^{\mu\nu}\gamma^{5}\chi F_{\mu\nu}$ (electric dipole EDM d).

We switch these operators on one at a time: the parameter space is spanned by the dark state mass m_{χ} and $\{\epsilon, \mu, d\}$.

Current mQ constraints

Millicharged states are strongly constrained:

- Between 0.1 and 100 MeV, beam dumps are most sensitive. A dedicated search was carried out at SLAC. Data from LSND and MiniBoone has been recast in terms of mQ particles.
- Collider constraints apply up to a few TeV (OPAL at LEP and CMS at LHC)
- Astrophysical bounds apply on particles $\lesssim$ 100MeV from supernovae, with stellar cooling constraints on particles $\lesssim$ 100keV.

Many more constraints apply on mQ that constitute the dark matter.

Current MDM/EDM constraints

Few constraints exist on dark states that do not constitute dark matter. The only bounds come from

- L3 at LEP
- Fixed-target experiments

Beam dump experiments

A beam dump fires a large number of particles at a thick target. Particles may be either produced promptly by interaction with the target, or through particle decays.

Charged pions are too long-lived, and are absorbed in the target before decaying. This reduces the light neutrino background compared to other fixed-target experiments, e.g. CHARM-II.

Neutral pions and heavy vector mesons still decay quickly enough to produce dark states of interest.

If the particles are sufficiently weakly coupled, they will traverse the shielding that attenuates the background and make it to a detector.

BEBC WA66 experiment

The BEBC detector was 404m downstream of 2.72×10^{17} protons of 400 GeV from the CERN SPS.

The detector was 16.6 m^3 of a neon-hydrogen mixture, in which a dedicated search for elastically scattered electrons was carried out.

Only one candidate event was observed; careful estimates of the background predict 0.5 ± 0.1 events.

Production mechanisms

The main production mechanism in a beam dump is meson decay; direct Drell-Yan production is subdominant for nearly all relevant masses m_χ.
The specific decay channel depends on whether the meson is a pseudoscalar or vector meson.
Pseudoscalars $\mathfrak{s}$ undergo a three-body decay $\mathfrak{s} \to \gamma\bar{\chi}\chi$;
vectors $\mathfrak{v}$ undergo two-body decay directly to a dark-pair $\mathfrak{v} \to \bar{\chi}\chi$.
Meson production rates are handled with MadGraph. The subsequent decay is handled by MadDump plug-in.

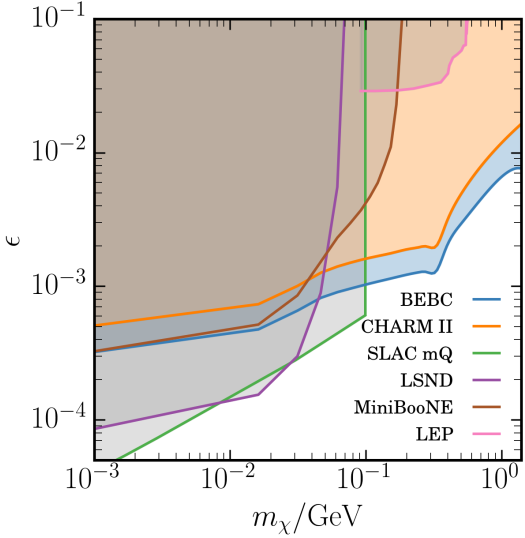
Detection mechanism

The dominant detection mechanism is elastic scattering off electrons. Deep inelastic scattering (DIS) is subdominant for all relevant masses. The total number of scattering events $N_e\chi$ at a particular electron energy T_e is

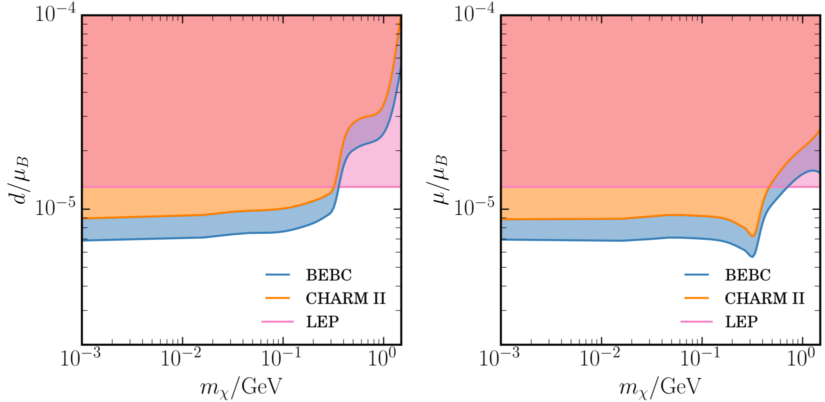
$$N_{e\chi}(T_e) = \varepsilon_{\rm geo} L n_e \int dE_\chi \frac{dN_\chi}{dE_\chi} \sigma_{e\chi}(E_\chi)$$

where $\varepsilon_{\rm geo}$ is the geometric acceptance of the detector, L is the longitudinal detector length, n_e is the number density of electrons and N_χ is the number of dark states produced.

Millicharge bounds



EDM and MDM bounds



Conclusions

- Past neutrino experiments provide the strongest direct constraints on electromagnetically coupled dark states in the sub-GeV region.
- Of currently analysed experiments, BEBC places the strongest constraints.
- Further analyses of neutrino data should be carried out, e.g. in terms of bounds on heavy neutral leptons.