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PIP2-BD: Searches for new physics with a stopped-pion source at the Fermilab accelerator complex

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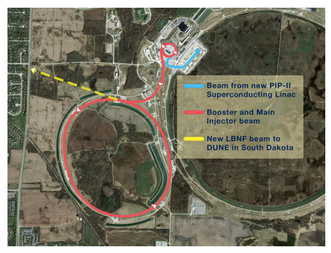
Fermilab's PIP-II Accelerator Project

- Upgrade to Fermilab's accelerator complex driven by DUNE physics goals
- PIP-II accelerator capable of 1.6 MW at 800 MeV proton energy CW
  - 1.1% of protons needed to support DUNE
- Leverage existing upgrade plans to search for new physics at Fermilab

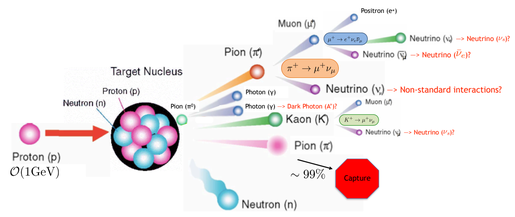


PIP-II as a stopped-pion source

- A stopped-pion neutrino source is generated when protons collide with a fixed target
  - Produces charged and neutral pions, which decay at rest
  - Produce three flavors of neutrinos with very well know energy profile
- Low mass dark sector searches are enabled at PIP-II with the addition of an accumulator ring
  - Studied three possible accumulator ring scenarios
- PIP-II Accumulator Ring (PAR), Compact PIP-II Accumulator Ring (C-PAR), and Rapid Cycling Synchrotron Storage Ring (RCS-SR)
- PAR and C-PAR can be built within the decade at modest cost
- RCS-SR is on a longer-term timescale and more expensive

Facility	Beam Energy (GeV)	Repetition Rate (Hz)	Pulse Length (s)	Beam Power (MW)
PAR	0.8	100	2×10^{-6}	0.1
C-PAR	1.2	100	2×10^{-8}	0.09
RCS-SR	2	120	2×10^{-6}	1.3

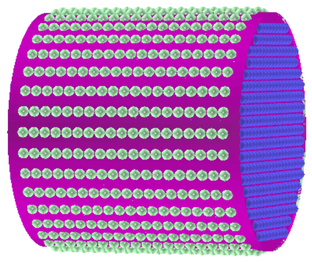
Accelerator scenarios studied as part of PIP2-BD. PAR and C-PAR are realizable within the start of the PIP-II era and RCS-SR is an upgrade on the timescale of the FNAL Booster Replacement



A stopped-pion neutrino source, showing how the proton interactions within the target material produces neutrinos

The PIP2-BD Detector

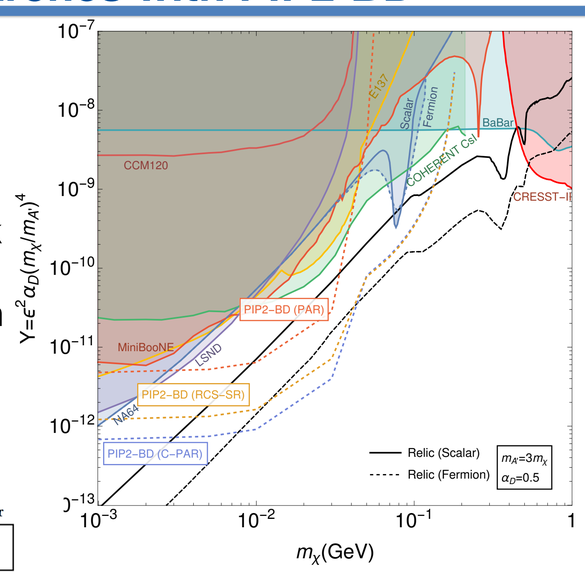
- Consider 100-ton scale single-phase scintillation only liquid argon detector
  - 4.5 m cylinder inside 6x6x6 m^3 box
- Custom Geant4 simulation to study light collection and simulating possible backgrounds
- Surround sides and endcaps of detector volume with TPB-coated 8" PMTs



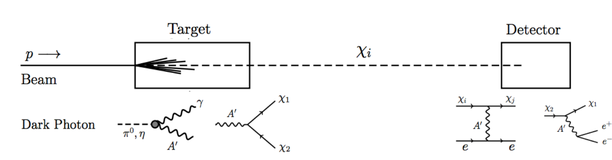
Active volume for the proposed PIP2-BD detector showing the photomultiplier tube configuration which was optimized to achieve a 20 keVnr threshold

Dark Sector Searches with PIP2-BD

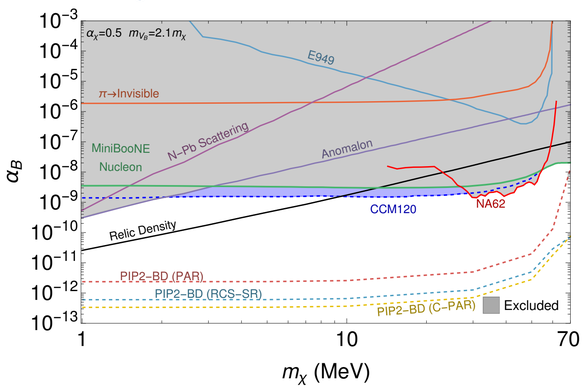
- Many possibilities for dark sector searches with a stopped-pion source
- Vector portal models produce dark sector mediators between Standard Model and dark sector in proton collisions with the target
  - Detection mechanism low energy nuclear recoil in LAr



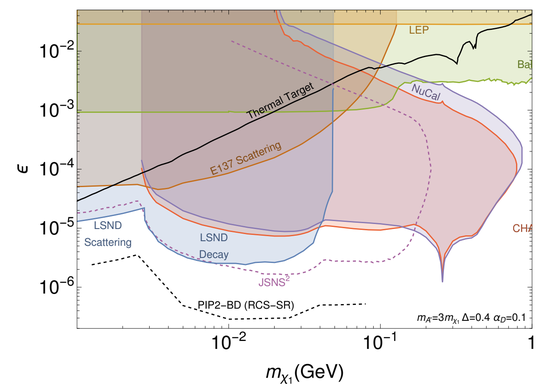
5-year run sensitivity of the PIP2-BD accelerator scenarios to the minimal vector portal kinetic mixing model . This scenario includes neutrino and steady-state background simulations



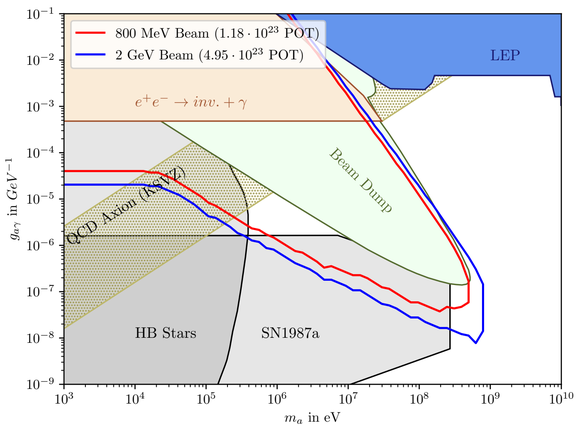
- Possibility of dark sector coupling to leptons or quarks (leptophobic)
- Understanding beam-related backgrounds important!
- Inelastic dark matter (iDM) model extends vector portal scenario to include two DM particles
  - Detection mechanism decay to e+e- or up-/down-scattering of DM off electrons in the detector
- Axion-like particles (ALPs) that couple to photons produced in beam dump via Primakoff process
  - Detectable via inverse Primakoff process or decay to two photons
- ALPs coupling to electrons detectable via inverse Compton, e+e- conversion, or decay to e+e-
- Snowmass White Paper submission: https://arxiv.org/abs/2203.08079



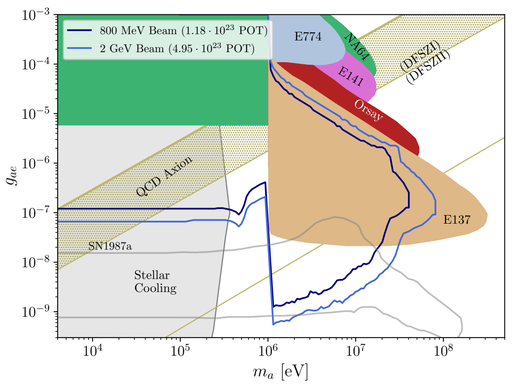
5-year run sensitivity of the PIP2-BD accelerator scenarios to the leptophobic vector portal model. This scenario includes neutrino and steady-state background simulations



5-year run sensitivity of the PIP2-BD RCS-SR scenario to the iDM model. The 3 event sensitivity is generated for each DM mass point without estimating backgrounds



PIP2-BD sensitivity to ALPs coupling to photons in both the PAR (red) and RCS-SR (blue) scenarios. The phenomenological sensitivity curve covers the important "cosmological triangle" and tests new parameter space for the QCD axion assuming a detector threshold of 100 keV



PIP2-BD sensitivity to ALPs coupling to electrons in both the PAR (dark blue) and RCS-SR (light blue) scenarios. The phenomenological sensitivity curve tests new parameter space for the QCD axion assuming a detector threshold of 100 keV

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