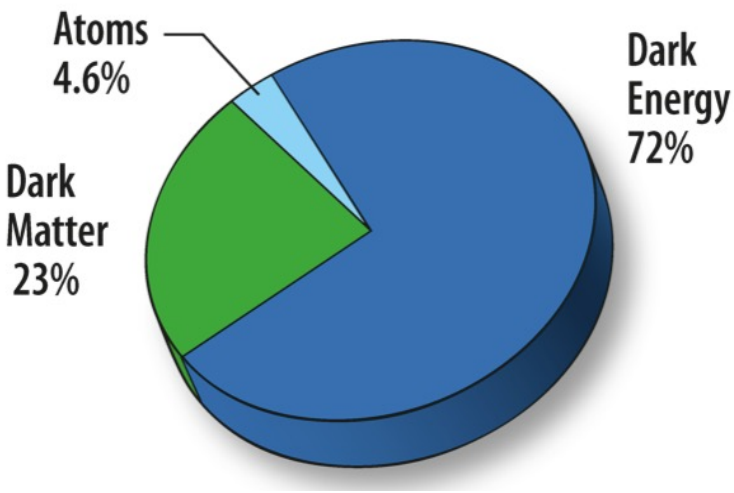
Search for Light Dark Matter with the Beam Dump eXperiment (BDX) at Jefferson Lab

- Intro to Dark matter
- BDX at Jefferson Lab
- Data from a pilot experiment (BDX-MINI)
- Limits from BDX-MINI

Elton S. Smith for the BDX Collaboration

Jefferson Lab and the College of William and Mary

Dark Matter



Dark matter is

- Non-luminous
- Non-absorbing
- Gravitationally active

$$\Omega_{DM} \sim 1/4$$

Possibilities for Dark Matter ?

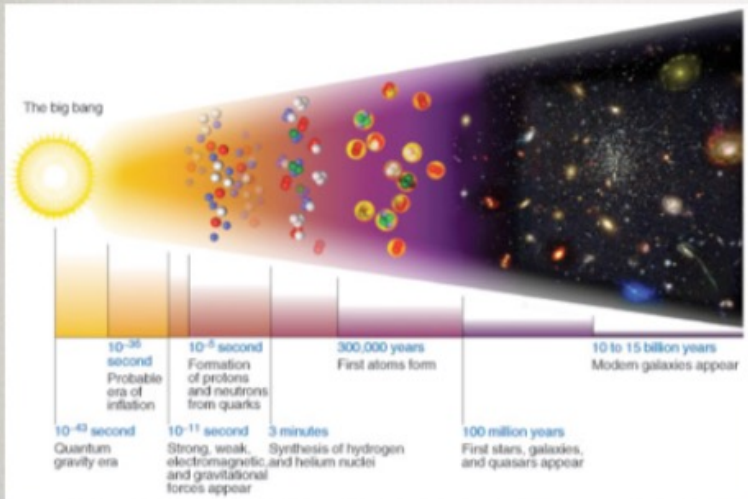
- Primordial black holes
- Axions
- Heavy neutrinos
- Light supersymmetric particles
- Weakly Interacting Massive Particles (WIMPs)
- Light Dark Matter (LDM)
- .....

Jungman Phys Rep 267 (1996) 195

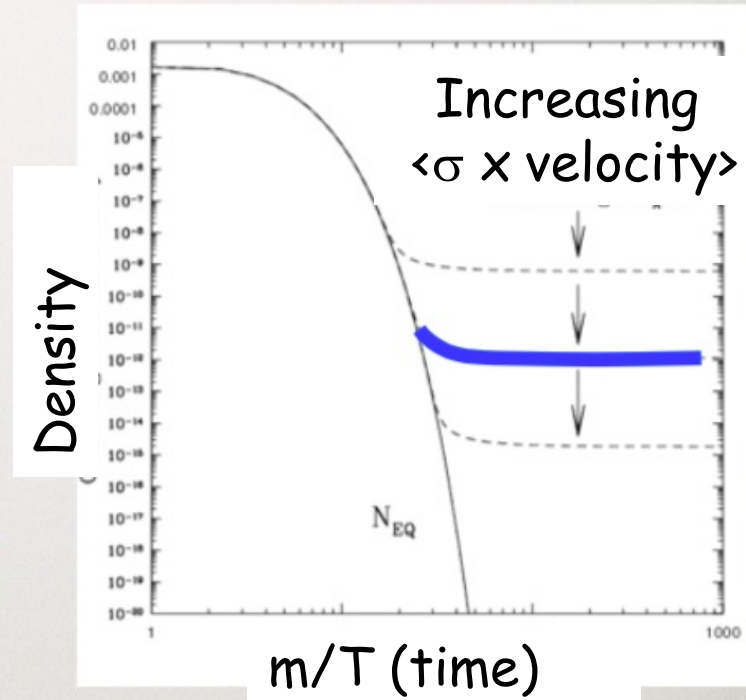
Jaeckel Ann Rev Nucl Sci 60 (2010) 405

See PDG Review of Dark Matter

Thermal cosmological origin

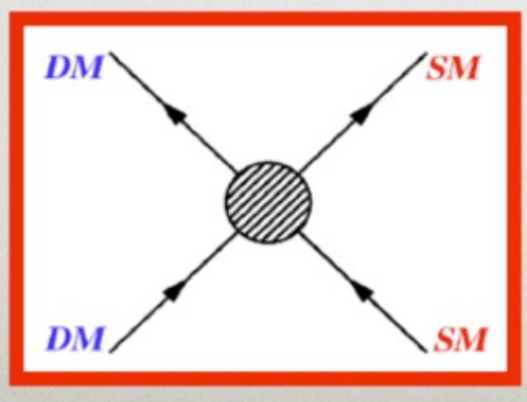


Eventually dark matter particles can't find each other to annihilate



As Universe cools below DM mass, density decreases as $e^{-m/T}$

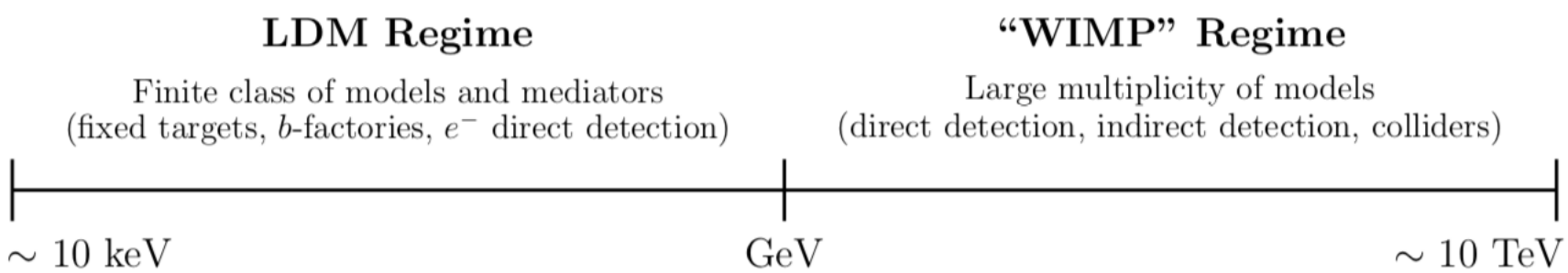
Dark Matter interacts with SM to stay in equilibrium…



and a (minimal) DM abundance is left over to the present day

Slide Credit: Phillip Schuster

Covering the possibilities



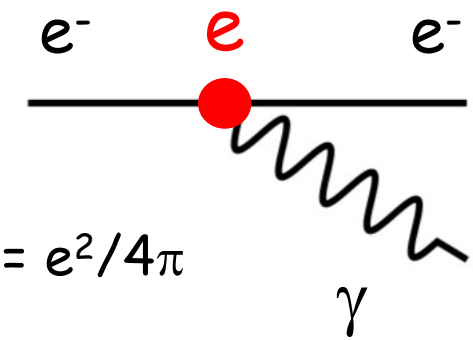
- "No room for a new Standard Model charged matter at the GeV scale."
- LDM requires new additional forces with light sub-GeV force carriers to produce the observed DM abundance.
- Extensions of Standard Model can provide DM candidates (WIMPs) which freeze out via SM gauge interactions.
- But… No candidates found so far

US Cosmic Visions hep-ph/1707.0459

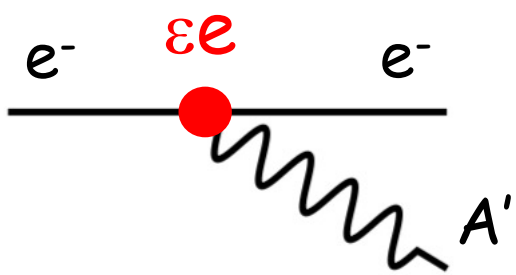
Standard Model - Dark Sector

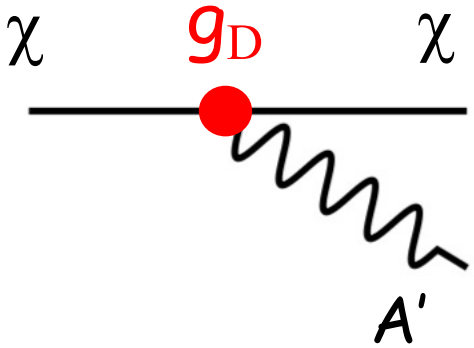
Portal

(Kinetic Mixing)

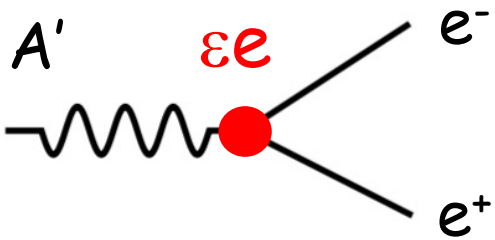


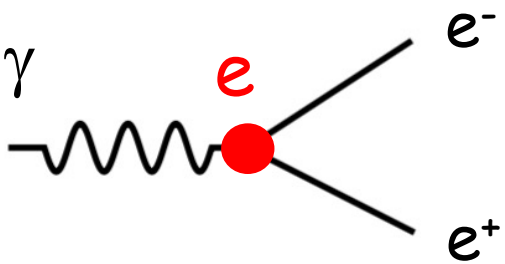
$\alpha = e^2/4\pi$

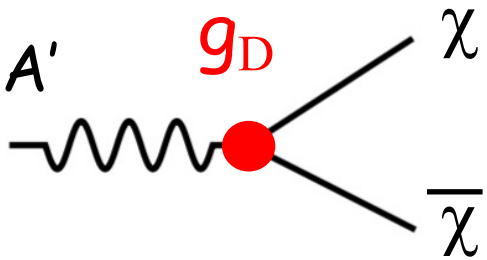




$\alpha_D = g_D^2/4\pi$

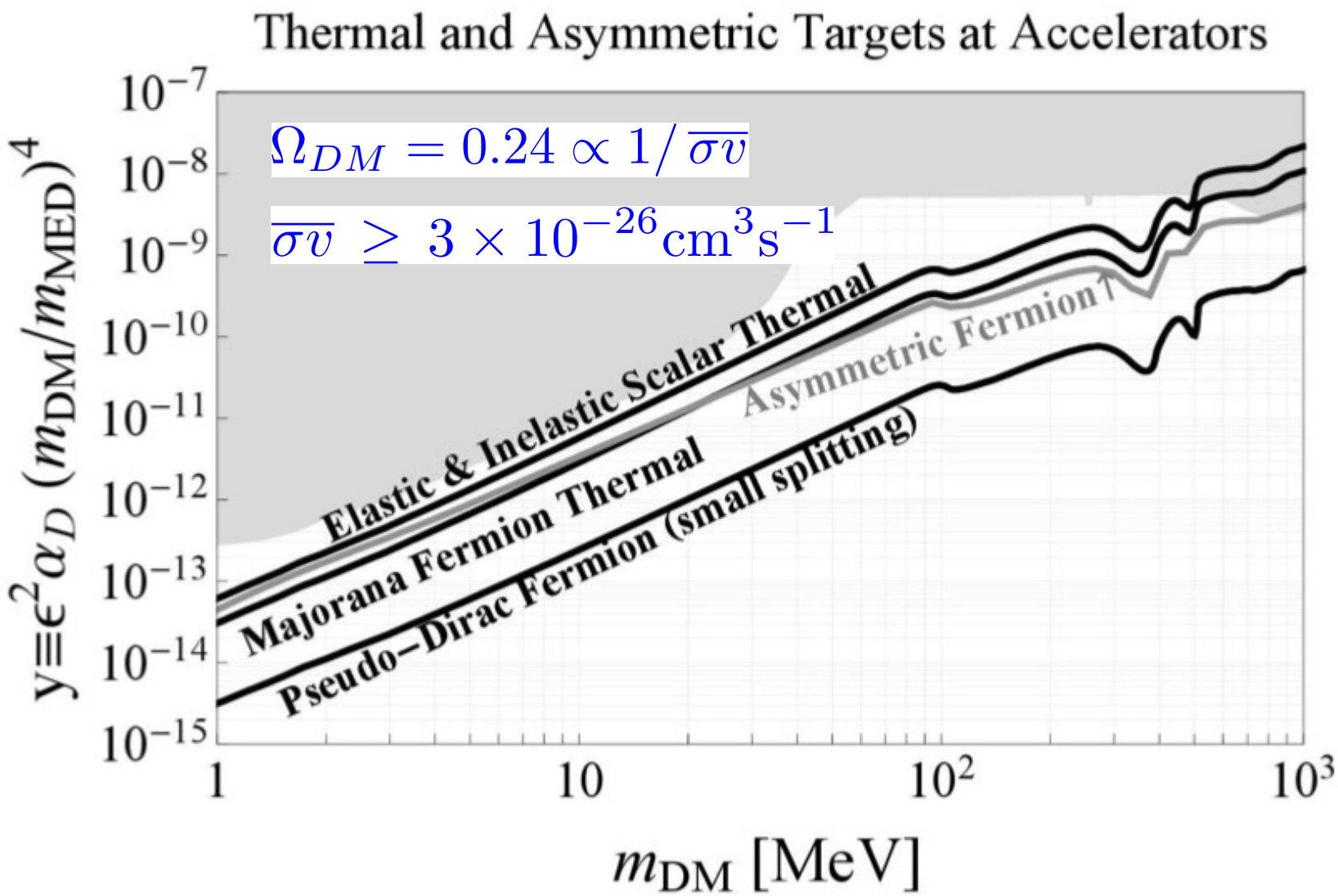




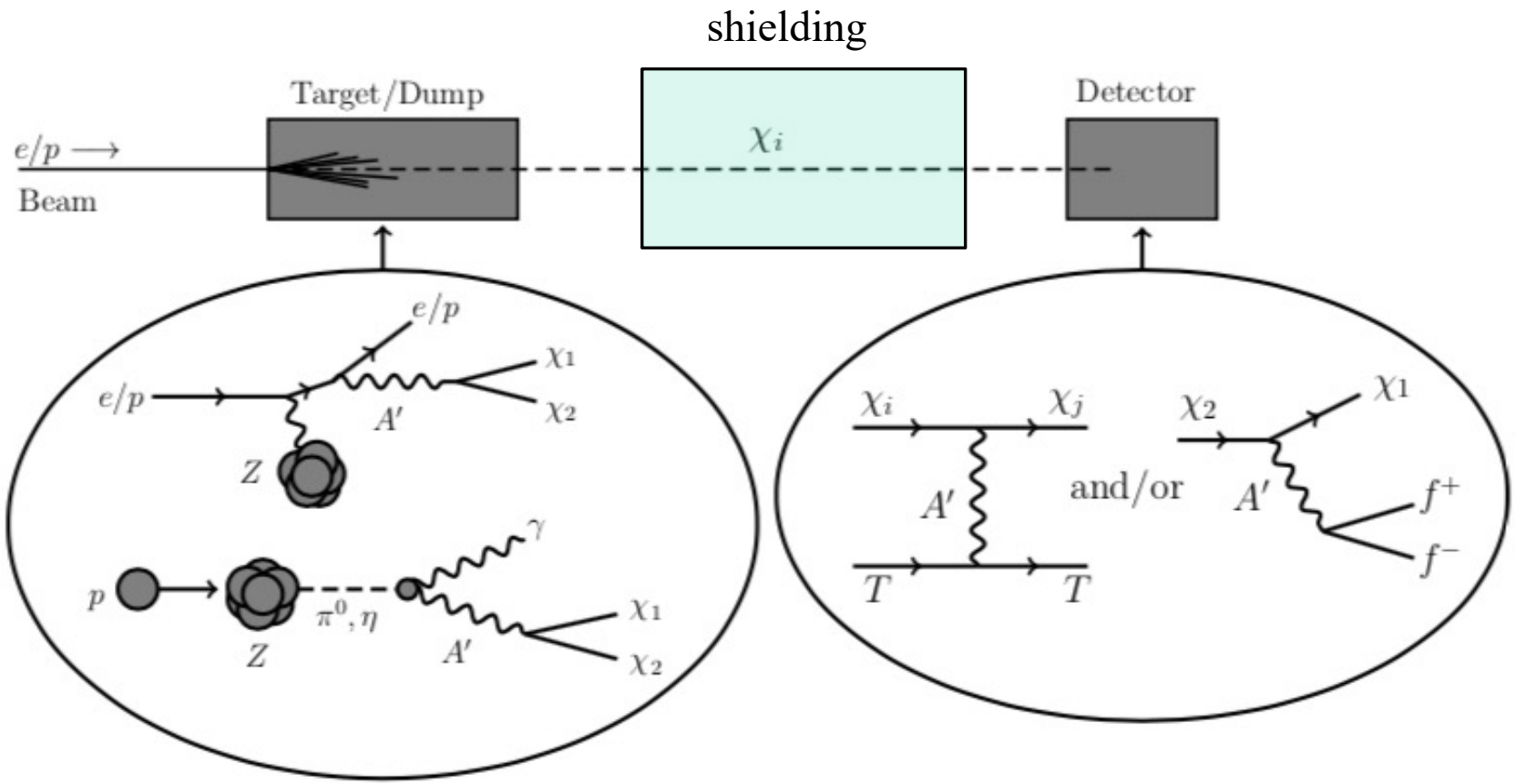


DM with thermal cosmological history

$y \sim \sigma v \times m_\chi^2$



Decays to dark matter "invisible decays"



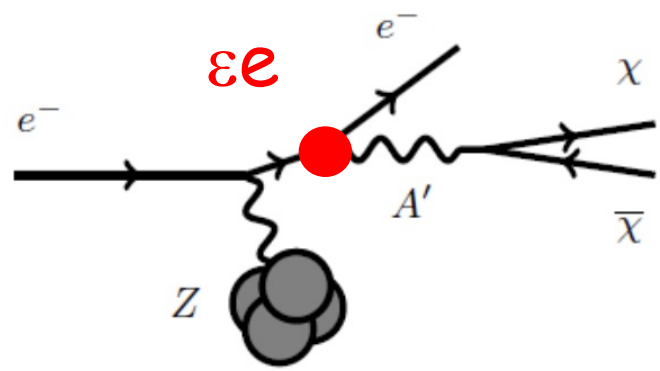
Izaguirre PRD 96 (2017) 055007

Beam Dump Experiments

Izaguirre PRD 88 (2013) 114015

- Parasitic to experimental program. Use electrons that are otherwise thrown away
- Produce "invisible decays" of heavy photon (Beam Dump)

$$A' \rightarrow \chi\overline{\chi}$$

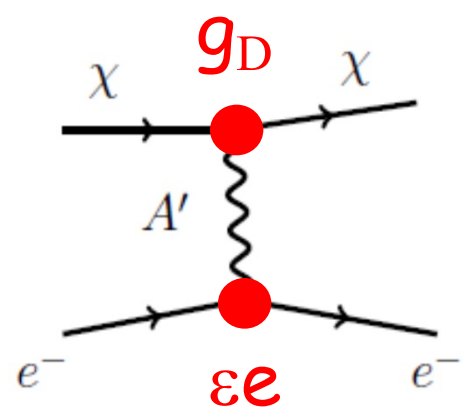


- Detect dark matter particle interaction (Experiment Detector)
- Signature is EM shower E > 0.5 GeV

$$y = \epsilon^2 \alpha_D (m_\chi / m_{A'})^4$$

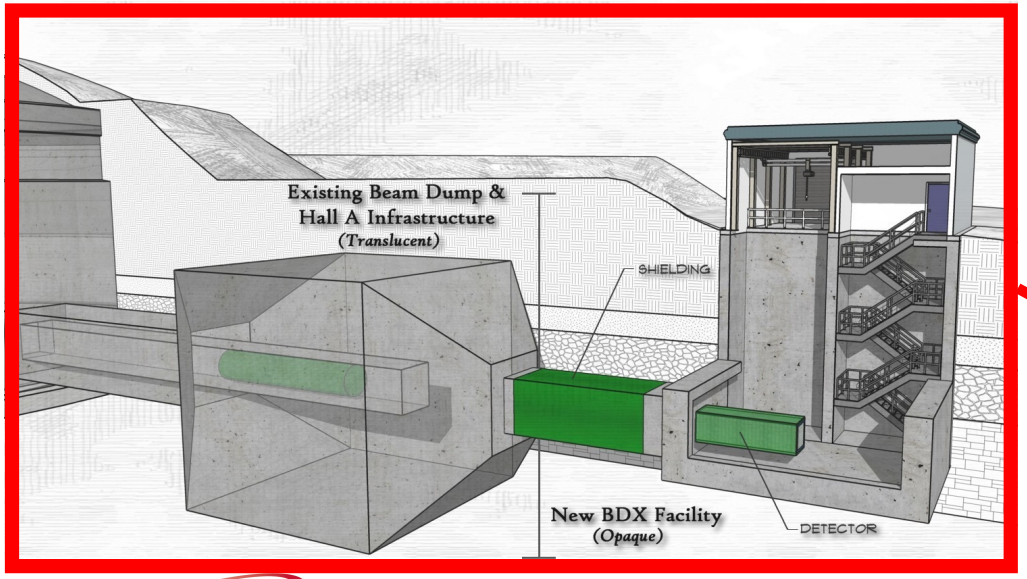
$$\text{Yield} \sim y^2 \times \frac{1}{\alpha_D} \times \left(\frac{m_{A'}}{m_\chi}\right)^4$$

($m_{A'} > 2\, m_\chi$)



Location of BDX at Jefferson Lab

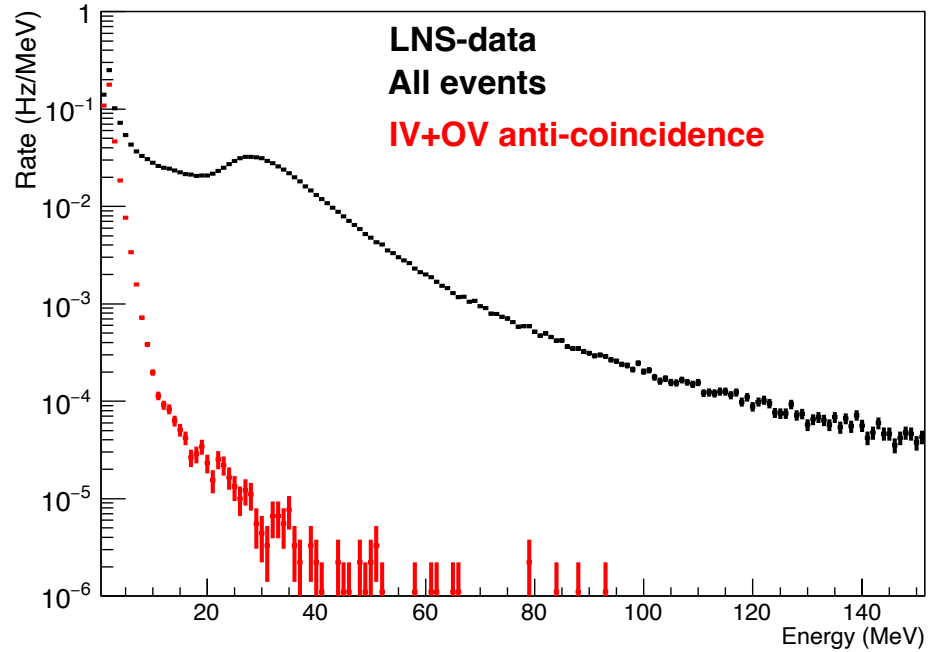
- New underground facility behind Hall A
- Increased shielding from beamdump
- Beam energy ~ 11 GeV
- Beam current ~ 65 μA
- Integrated charge ~ 10^{22} EOT (41 weeks)



Expected BDX backgrounds

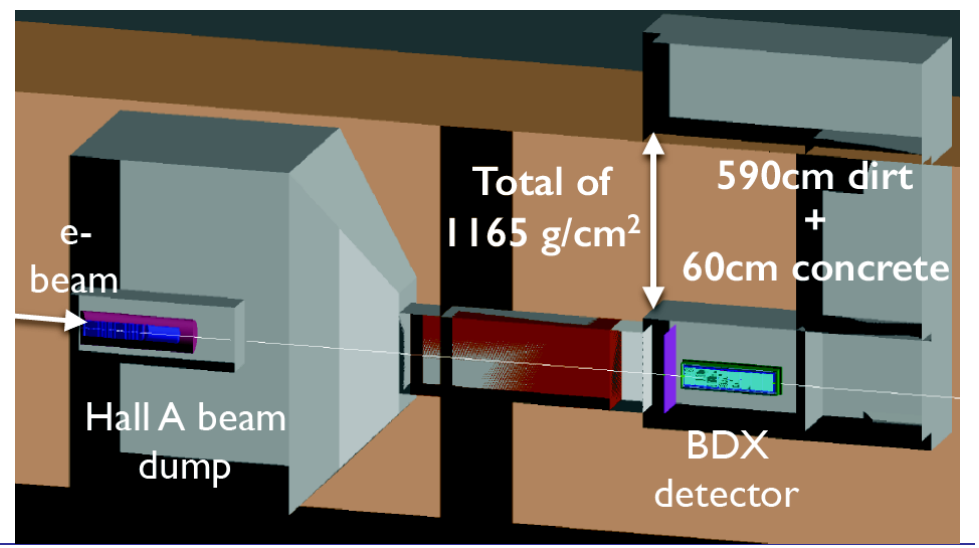
Cosmogenic: data-driven estimate

- Cosmic muons rejected by vetoes
- Neutrons absorbed by overburden
- Based on data at INFN-LNS (Catania): B_c = 5 (Th = 0.3 GeV)

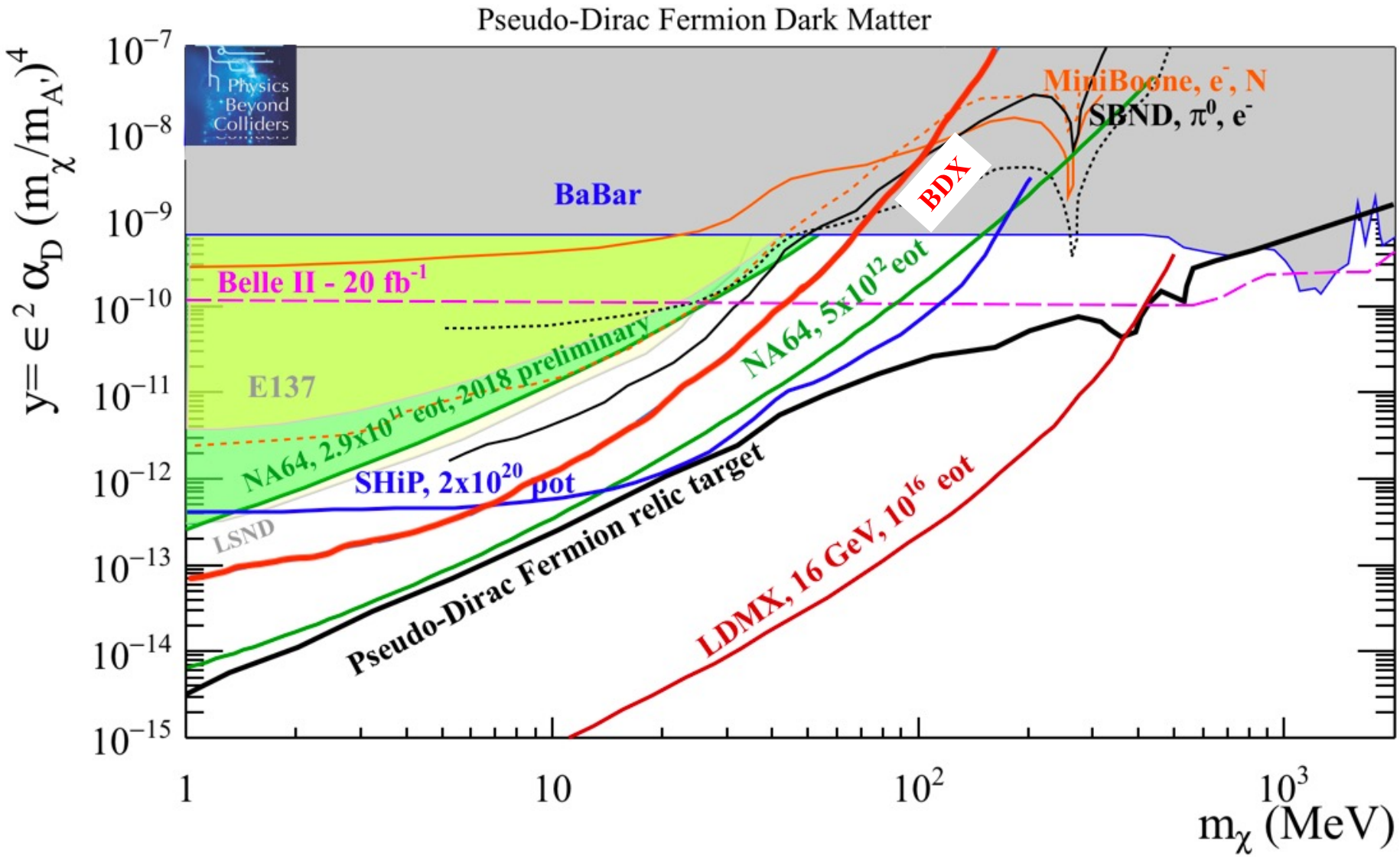


Beam-related backgrounds

- Detailed simulations (FLUKA+GEANT4+GENIE)
- B_ν = 10 for EOT=10^{22}
- All other SM particles absorbed by 6.6 m Fe and 2 m of concrete



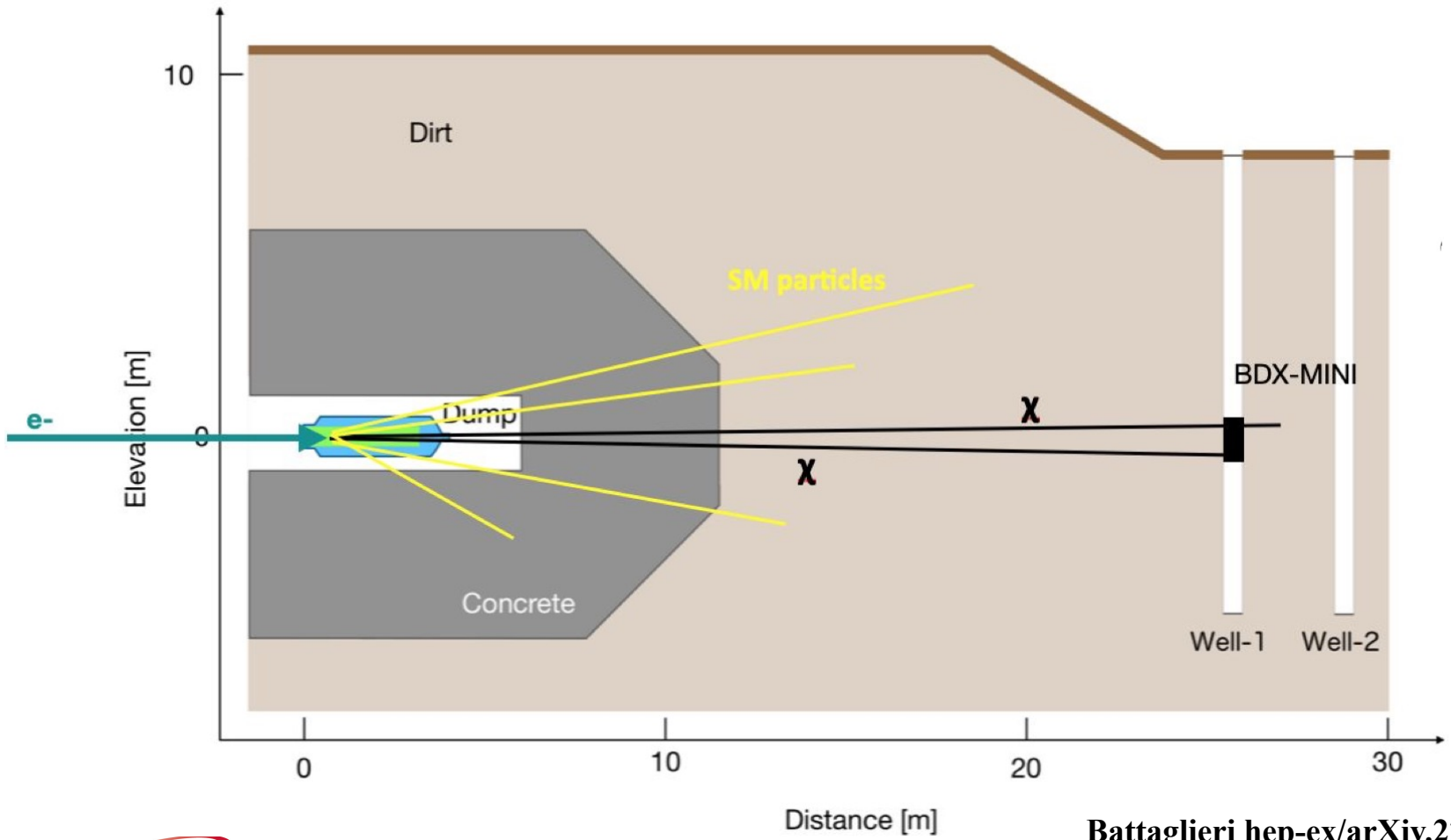
Reach of existing and proposed experiments



CERN-PBC-REPORT-2018-007 p. 86 hep-ex/arXiv.1901.09966

Pilot experiment: BDX-MINI

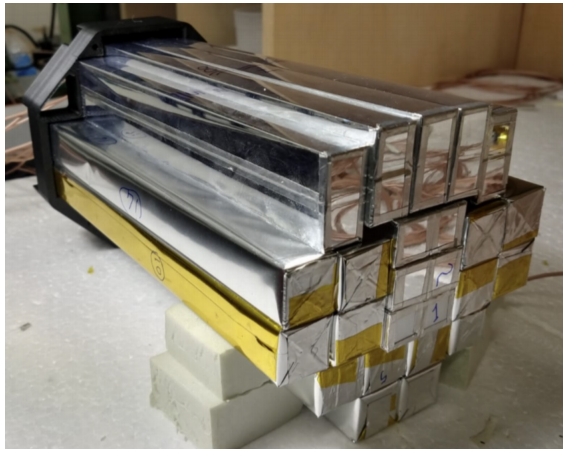
- Operated for about 6 months in 2020
- Experimental Parameters: E_e = 2.2 GeV, I = 150 μA, EOT = 2.5×10^{21}
- Shielding: 5.4 m concrete and 14.2 m of earth



Battaglieri hep-ex/arXiv.2208.01387

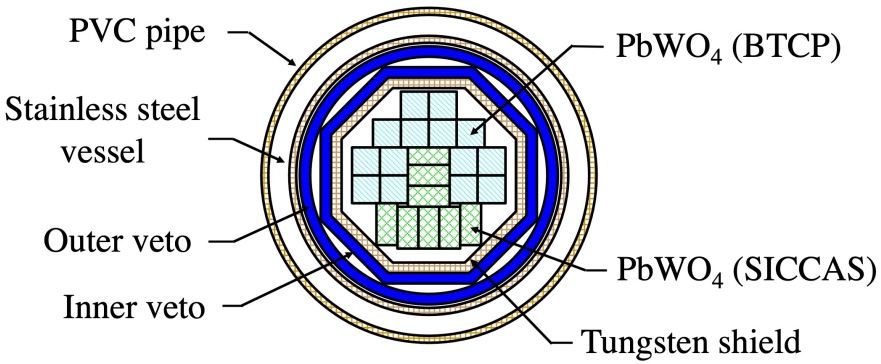
Detector based on BDX modular design

Crystal based detector



- Signal requirements
  - Sensitivity to EM showers
  - Low thresholds
  - Compact footprint and good segmentation

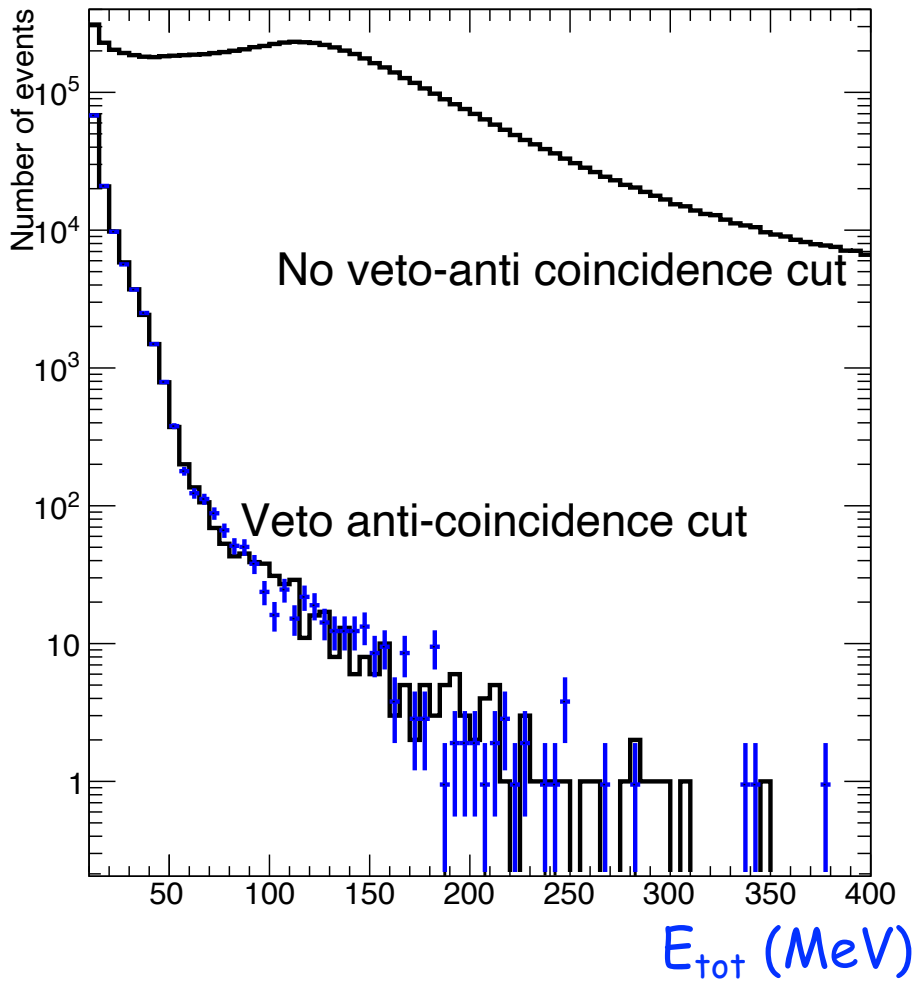
- Background rejection
  - High efficiency, fast timing
  - Hermetic
  - Three layers



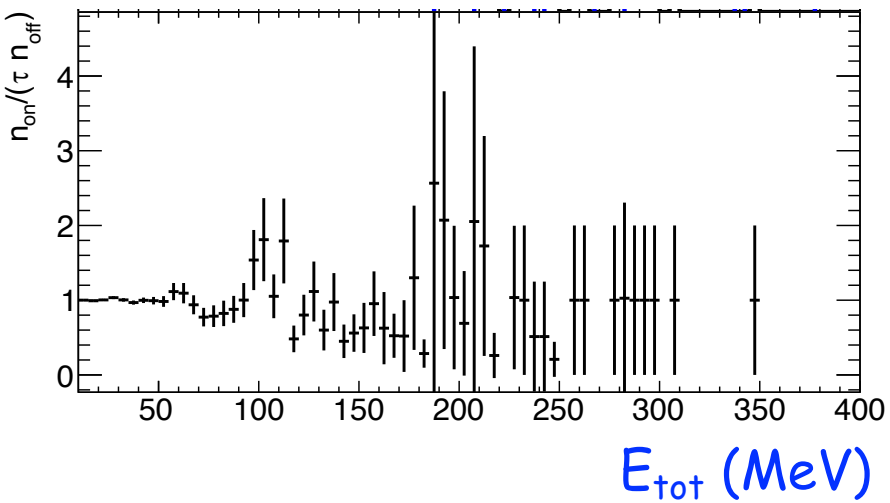
Battaglieri Eur. Phys. J C 81 (2021) 164

Battaglieri NIMA 925 (2019) 116

Beam on and Beam off, response to veto

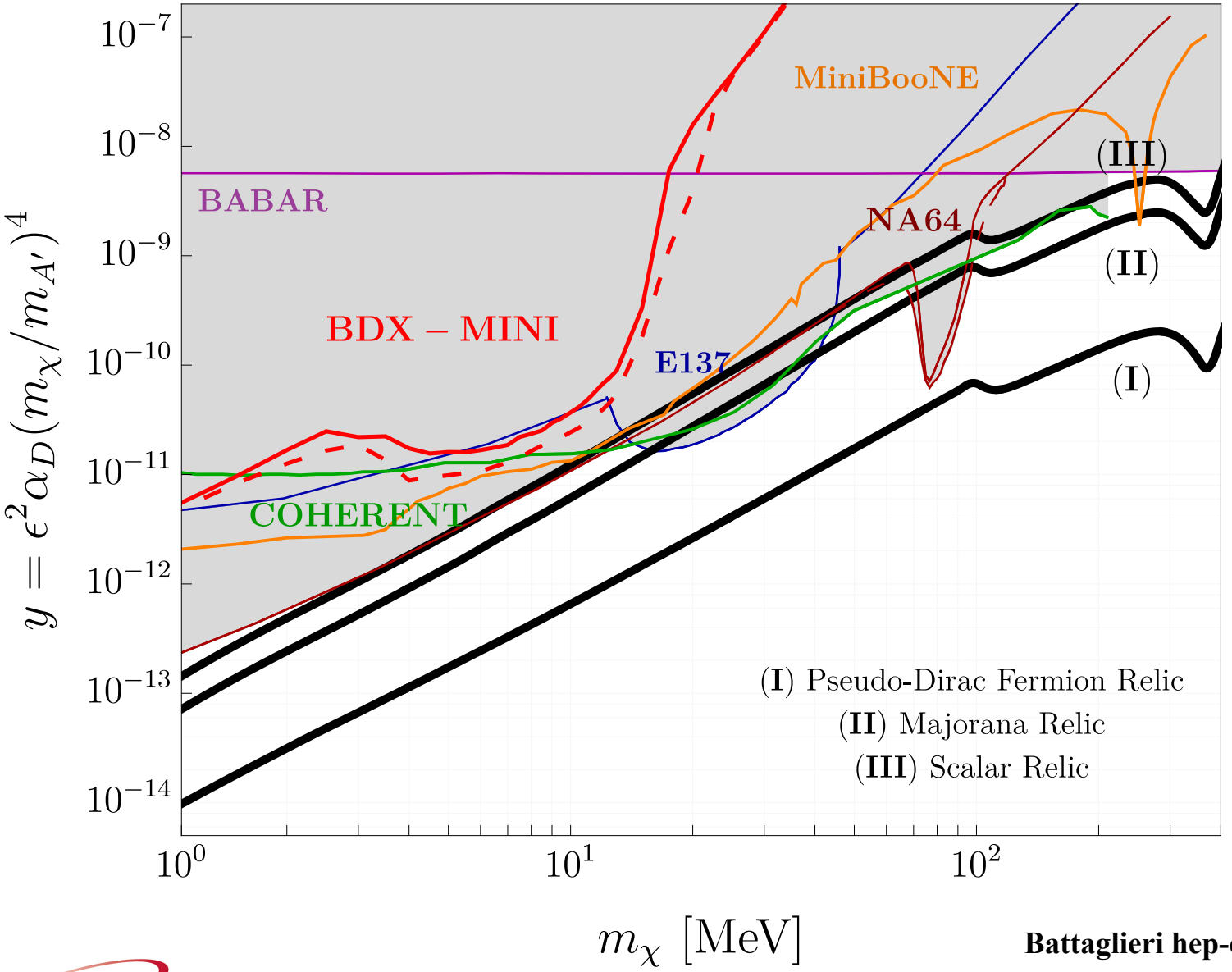


Ratio beam on/off



All data consistent with cosmogenic background

Parameter space excluded by BDX-MINI



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Summary

- Beam-dump experiments are sensitive to Dark Matter with masses ~ 1-1000 MeV and probe regions of the parameter space that are not covered by visible decays of dark photons.
- The BDX experiment is approved to run parasitically at Jefferson Lab for 41 weeks at ~11 GeV, which will allow it to collect ~10^{22} electrons on target. The full experiment is awaiting funding.
- A pilot experiment, BDX-MINI, took data for 6 months while Hall A was operating a low energy (2.2 GeV), which has allowed us to set limits close to existing boundaries in the parameter space.