Global Fits of sub-GeV Dark Matter with GAMBIT

Beam Dump and Fixed Target Experiments

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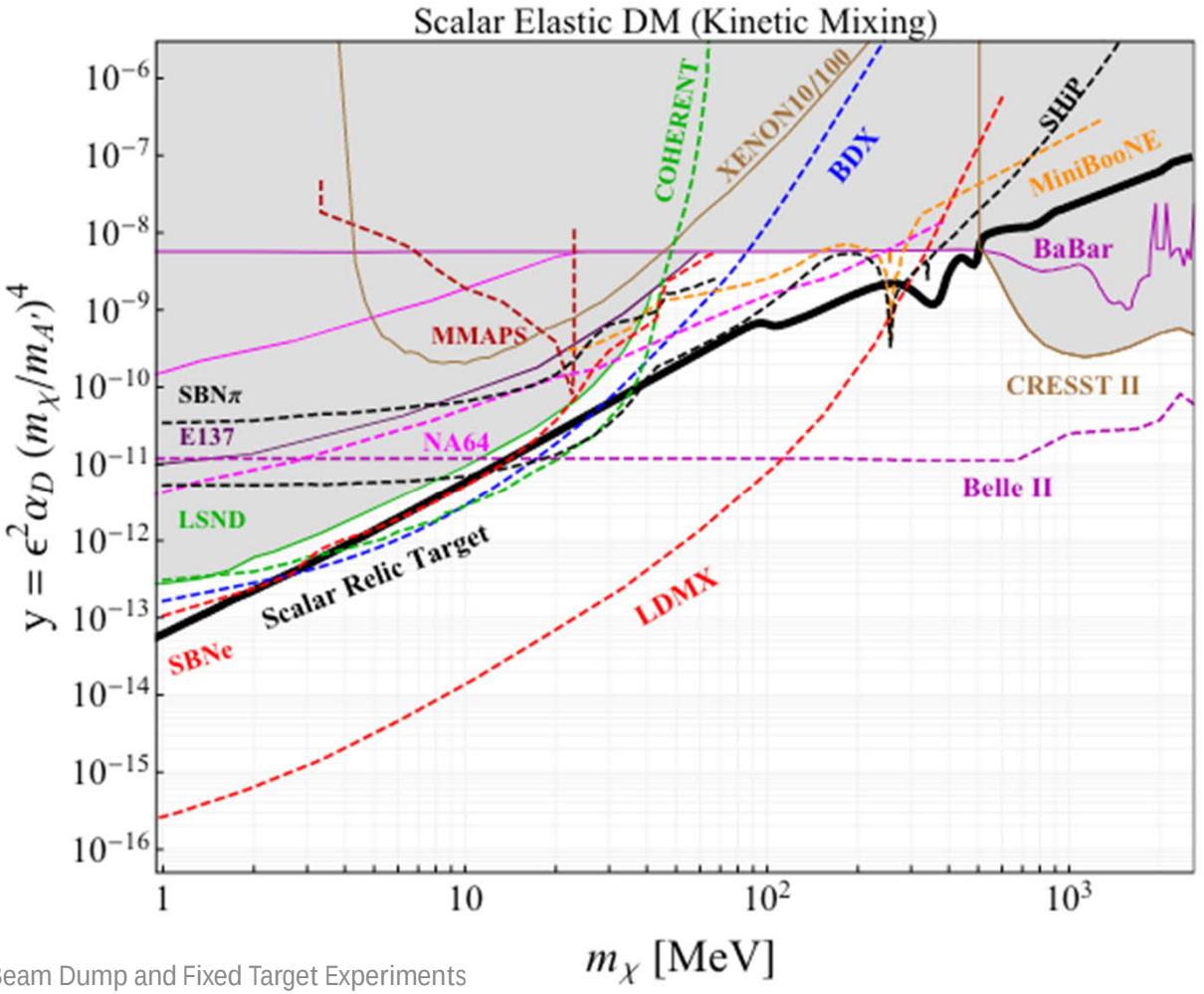
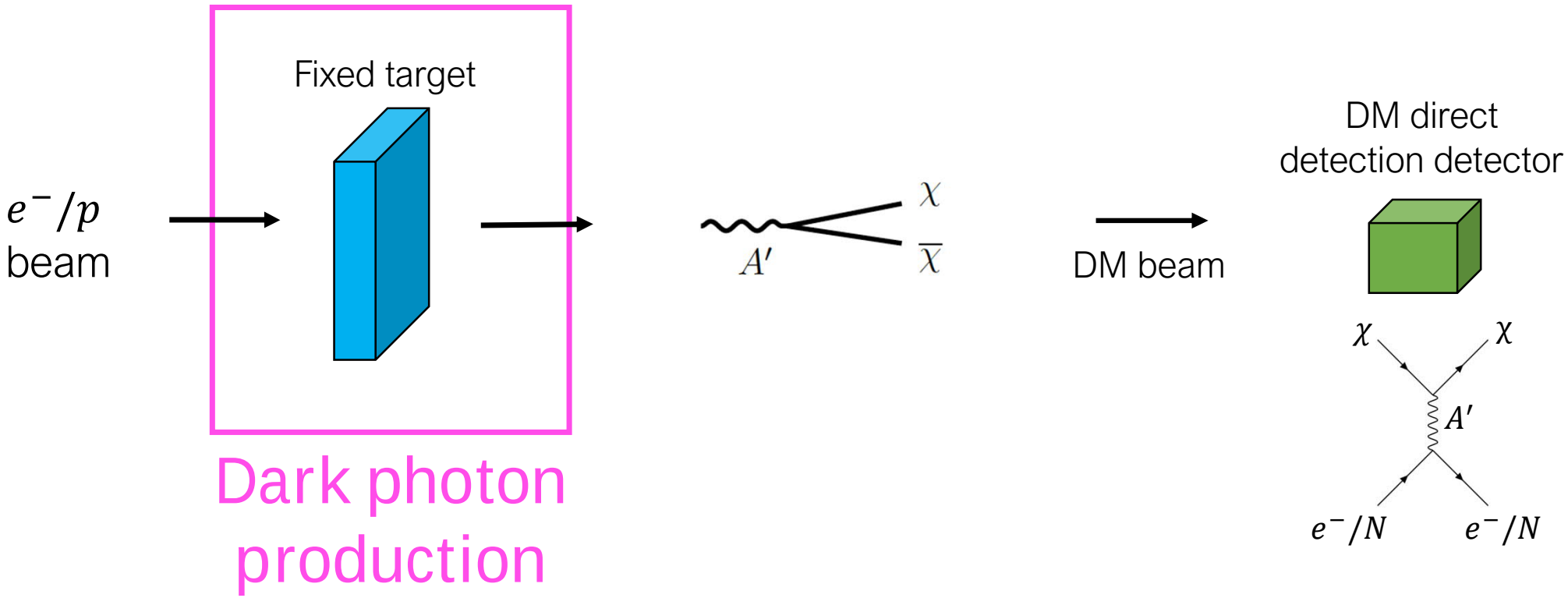
Accelerator Based DM Experiments

- Complementarity with direct detection experiments
- Types
  I. beam dump
  II. missing momentum/energy
  III. missing mass
  IV. direct dark photon search
  (visible dark photon decay)



Beam Dumps (Electron and Proton)



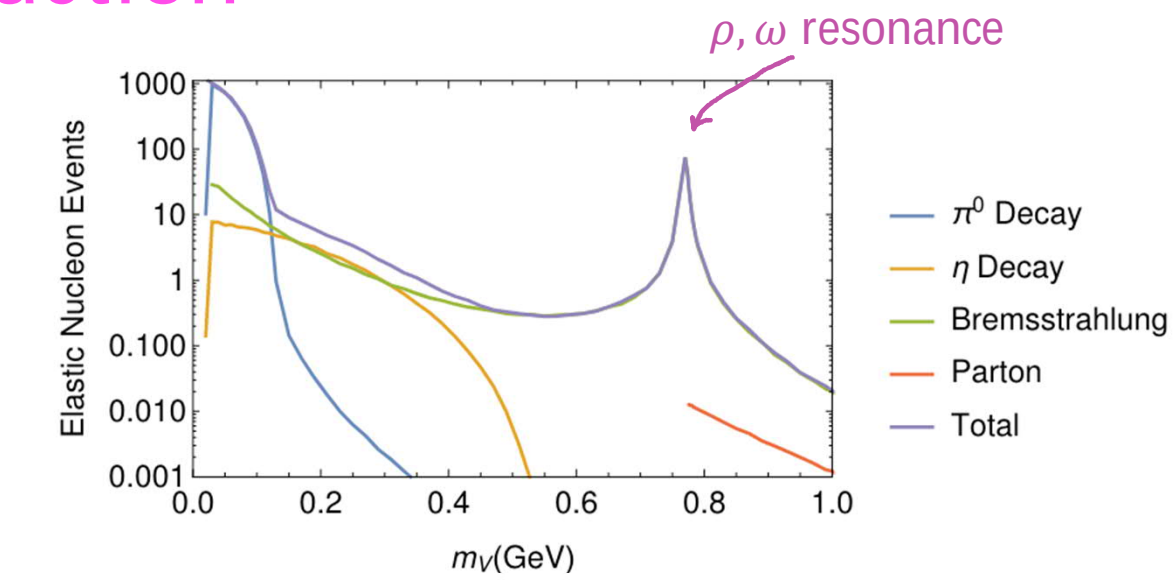
Beam Dumps (Electron and Proton)

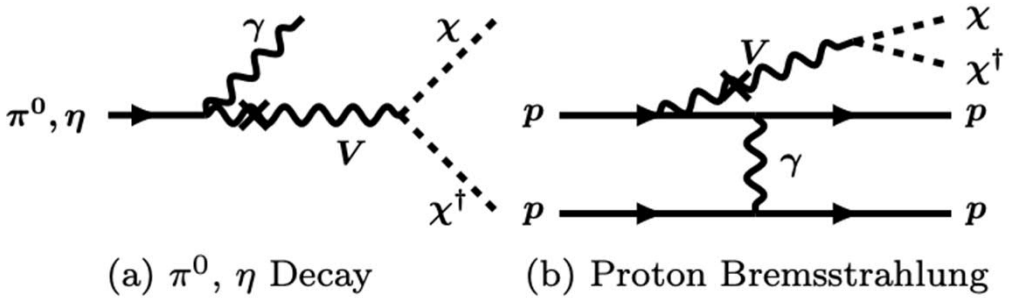
Dark Photon/DM Production

i. Mesons from proton beam – nucleon target interactions
   i. $\pi^0, \eta \to \gamma A', A' \to \chi\chi$

ii. Proton/electron dark bremsstrahlung
   i. $pN \to pNA'$
   ii. resonant vector meson mixing

iii. Direct production through parton level processes
   i. relevant for $m_{A'} > 1$ GeV





(a) π^0, η Decay (b) Proton Bremsstrahlung

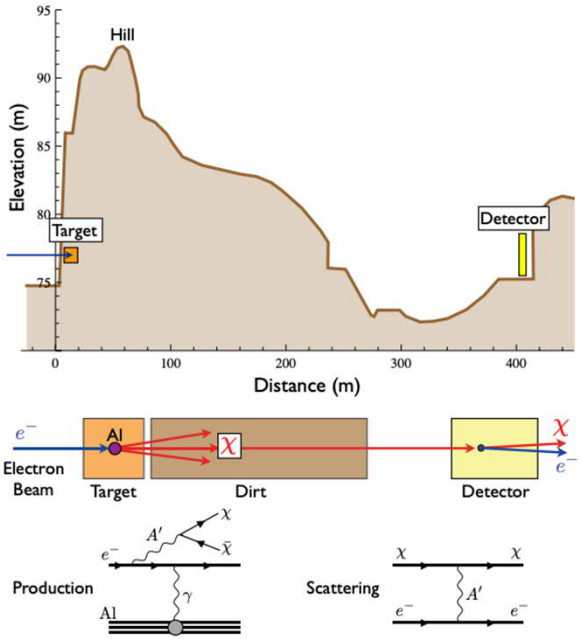
Beam Dumps (Electron and Proton)

arXiv:1107.4580

E137

arXiv:1406.2698

- DM produced from electron-target collisions
- 20 GeV beam incident on a set of aluminum plates interlaced with cooling water.



LSND

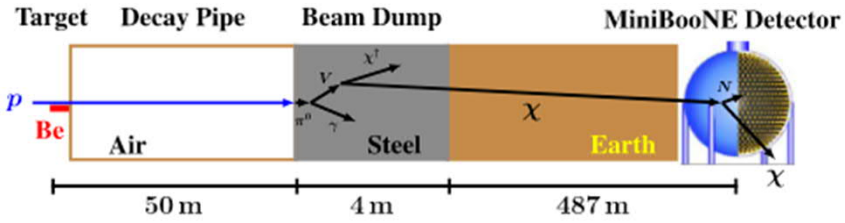
arXiv:hep-ex/0101039

- pions produced by impacting an 800 MeV proton beam onto a water or metal target
- $\pi^0 \to A'\gamma, A' \to XX$

MiniBooNE

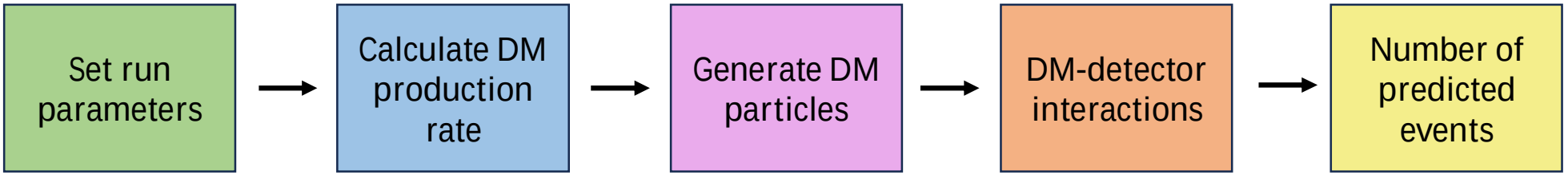
arXiv:1807.06137

- Designed to study short-baseline neutrino oscillations
- 8 GeV proton beam incident on a steel target
- Peak ~ 770 MeV (ρ mass)



Simulating Beam Dumps with BdNMC

arXiv:1609.01770



- Simulation parameters
- DM model parameters
- Experiment parameters

If DM particle intersects the detector:

- Calculate $\sigma_{\chi T \to \chi T}$, where T is e^- or N

Consider all relevant channels

- Meson decays:

$$N_{A' \to \chi\chi} = Br(X \to \chi\chi\gamma) \times N_{meson\_per\_POT} \times POT$$

- Proton bremsstrahlung

$$N_V = \mathbf{POT} \int_0^{\mathbf{ptmax}^2} dp_\perp^2 \int_{\mathbf{zmin}}^{\mathbf{zmax}} dz \frac{d^2 N_V}{dz dp_\perp^2},$$

$$N_{events} = \frac{N_{interactions}}{trials} \times N_{A' \to \chi\chi} \times p_{max} \times efficiency$$

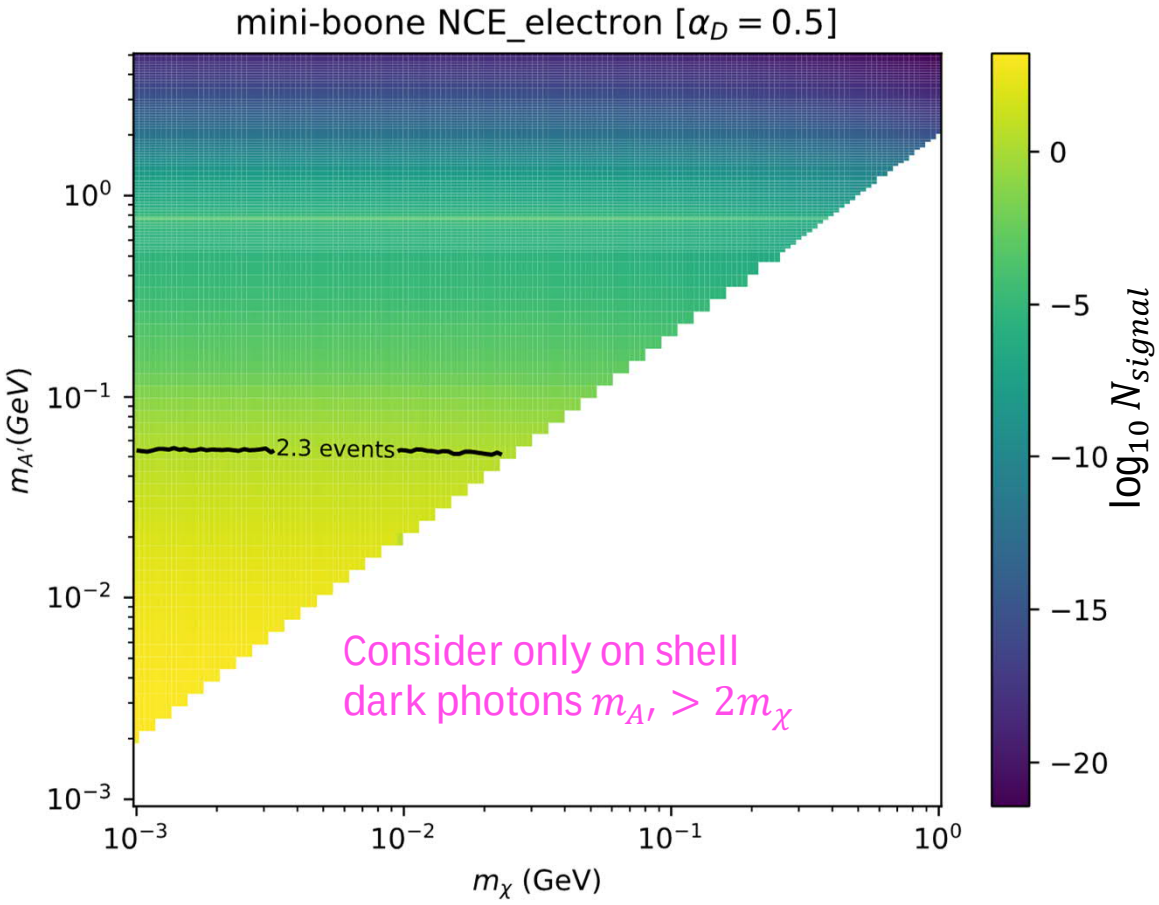
Implementation in GAMBIT ColliderBit

I. Calculate N_{signal} over 2 × 2 grid of varying $m_{A'}$ and m_χ

II. Interpolate grid

III. Scale for specific coupling:
- $N_{signal} \propto \epsilon^4 \times g_D^2 \times BR_{A' \to \chi\chi}(\epsilon, g_D)$

IV. Poisson likelihood from N_{signal}

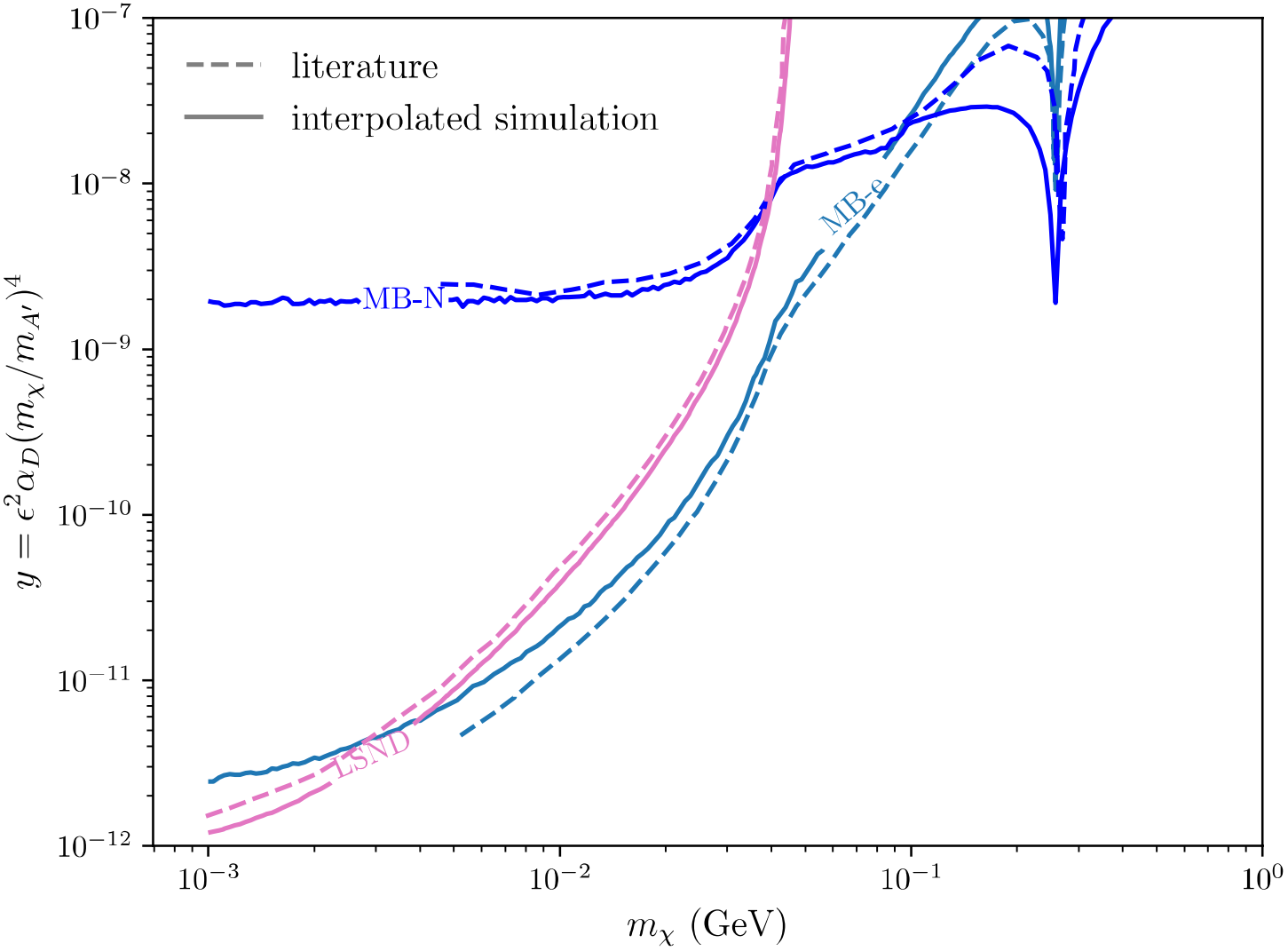


Two functions:
1. returns N_{signal}
2. returns Likelihood

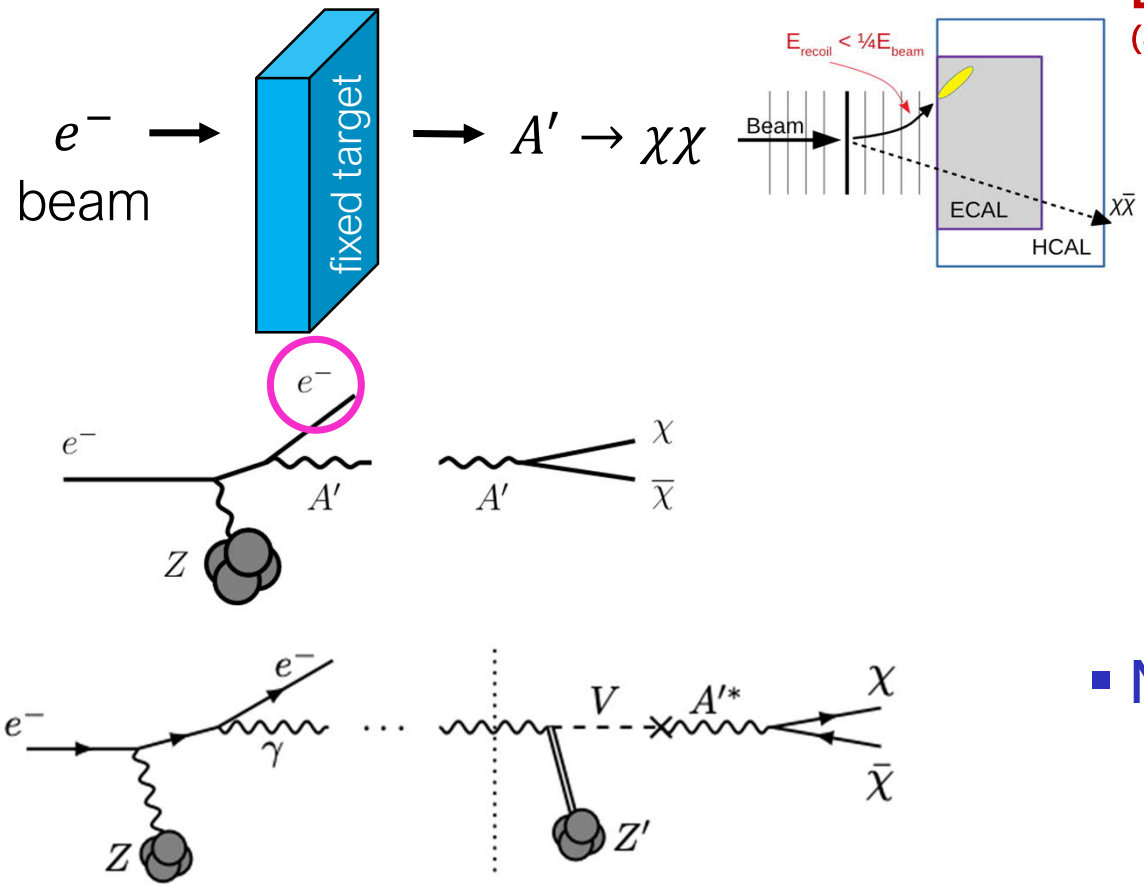
Beam Dumps

90% C.L. Exclusion Limits from MiniBooNE electron and nucleon scattering, and LSND

- Complex scalar DM
- $\alpha_D = 0.5$
- $\frac{m_{A'}}{m_\chi} = 3$



Missing Momentum/Energy Experiments



- **LDMX [Light Dark Matter eXperiment]** (arXiv:1808.05219)
  - Future Experiment
    - 2025: LESA delivers beam to LDMX allowing 4×10^{14} EOT
    - 2027: 10^{16} EOT
  - e^- incident on a thin tungsten target
  - charged particle tracker and calorimeters to measure DM signature
  - recoil electron pT accompanied by absence of other particle activity

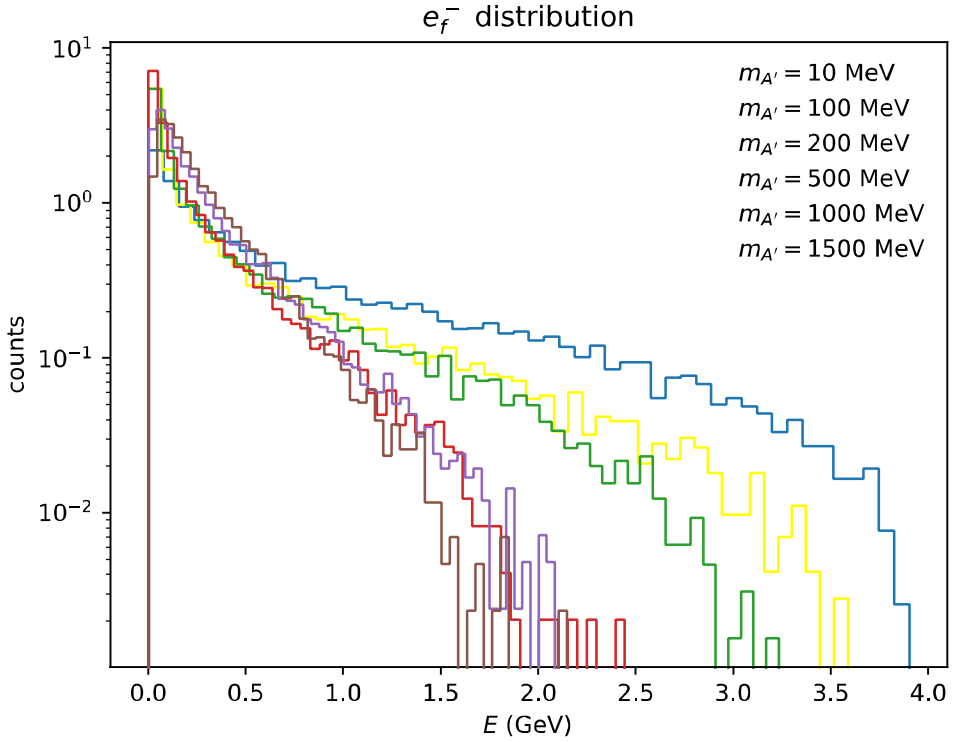
- **NA64** (arXiv:1906.00176)
  - 100 GeV electron beam incident on a lead target
  - Event: single electron produced and missing energy

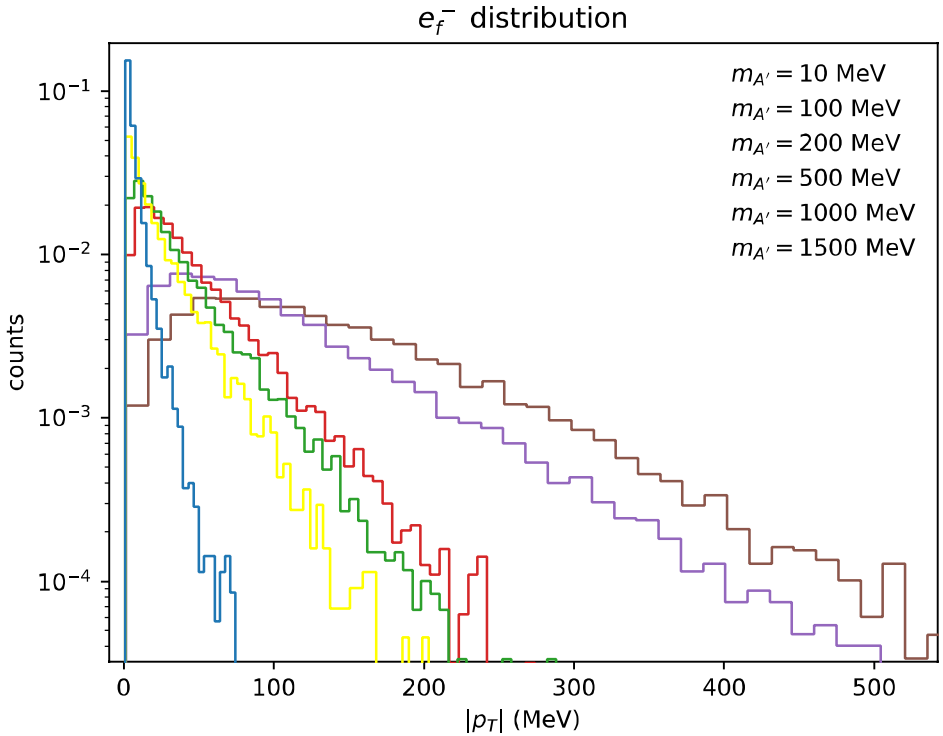
Missing Momentum/Energy Experiments

Final State Electron Distributions

Simulated using Madgraph

Use these distributions to calculate projected sensitivity of LDMX





Summary

- Interested in accelerator-based experiments probing sub-GeV DM
- Beam dump and missing momentum/energy exps provide competitive exclusion limits and discovery potential
- Work ongoing to implement simulations of beam dumps into sub-GeV DM GAMBIT branch
  - Interpolated data sets of $N_{events}(m_{A'}, m_{\chi})$
- Next:
  - Interpolated data sets of simulated p_T and E distributions at LDMX for likelihood calculation

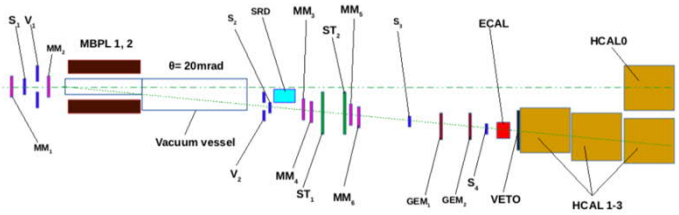
BACKUP SLIDES

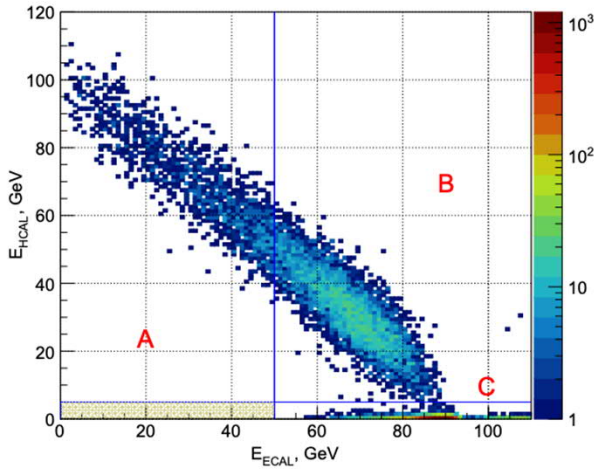
Electron Beam Dumps

NA64

arXiv:1710.00971

- 100 GeV electron beam incident on a lead target
- Event: single electron produced and missing energy

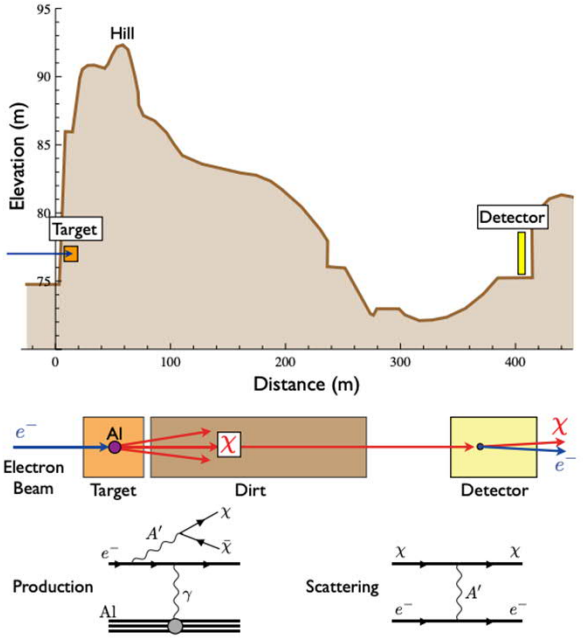




E137

arXiv:1406.2698

- DM produced from electron-target collisions
- 20 GeV beam incident on a set of aluminum plates interlaced with cooling water.
- Downstream detector



Light Dark Matter eXperiment (LDMX)

- Future fixed target missing momentum exp
  - 2025: LESA delivers beam to LDMX allowing 4×10^{14} EOT
  - 2027: 10^{16} EOT
- e^- incident on a thin tungsten target
- Charged particle tracker and calorimeters to measure DM signature
  - Recoil electron pT accompanied by absence of other particle activity