Beyond hadronic physics @JLAB

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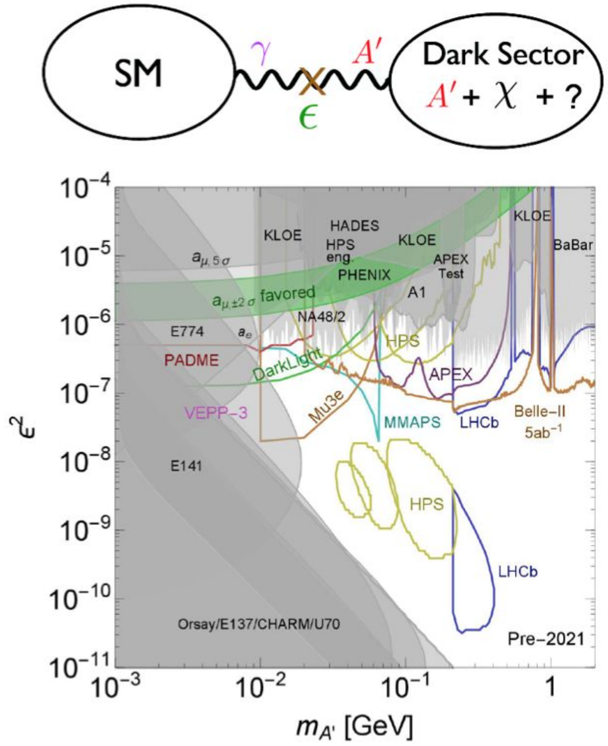
Outline

- ❖ Introduction to vector-mediated Light Dark Matter
- ❖ A' searches @ JLAB
  - ➢ APEX
  - ➢ HPS
  - ➢ BDX-mini and BDX
- ❖ LDM opportunities with a primary e+ beam
  - ➢ PADME-like
  - ➢ Missing energy approach
- ❖ Opportunities with secondary beams
  - ➢ Neutrino beam
- ❖ Conclusions

Vector mediated Light Dark Matter

- ❖ Plenty of cosmological/astrophysical observations: CMB anisotropies, galaxy rotation curves, gravitational lensing,cluster collisions…
- ❖ No hints on DM particle properties (mass, cross section)
- ❖ "**vector-portal**": DM-SM interaction through a new U(1) gauge-boson ("dark photon") coupling to electric charge[1]
- ❖ Model parameters:
  - ➢ Dark photon mass mA', and coupling to electric charge ε
  - ➢ Dark matter mass mX, and coupling to dark photon gD
- ❖ Experimental searches:
  - ➢ A comprehensive LDM experimental program must investigate both the existence of X particle and dark photons.



[1] For a comprehensive review: 1707.04591, 2005.01515, 2011.02157

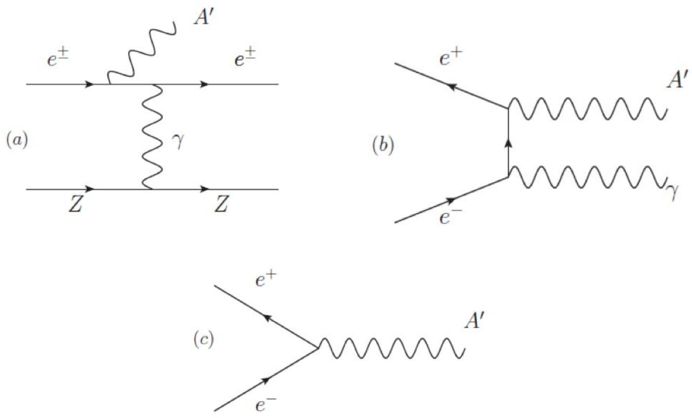
Dark photon production and decay

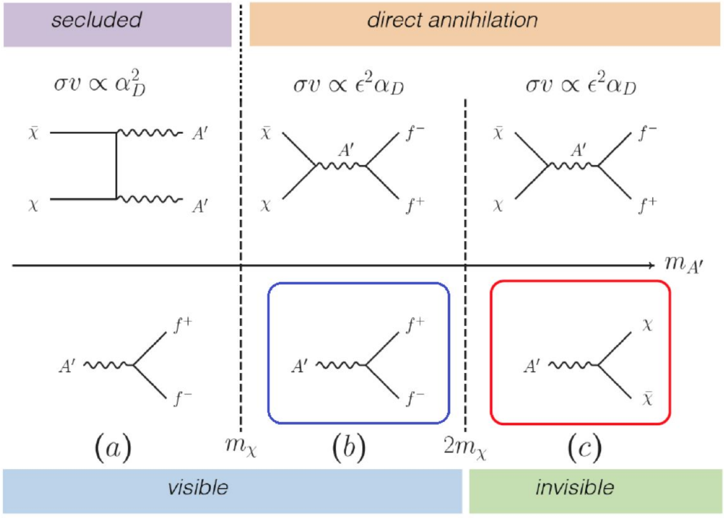
- **Three main LDM production mechanisms in fixed-target experiment:**

a) A'-stralung : scales as $\varepsilon^2 Z^2 \alpha^3$, forward-boosted A' emission

b) e+e- annihilation: scales as $\varepsilon^2 Z \alpha^2$, forward-backward emission in the CM

c) Resonant e+e- annihilation: scales as $\varepsilon^2 Z\alpha$. Breit-Wigner like cross section with $M_{A'} = \sqrt{2 m_e E}$





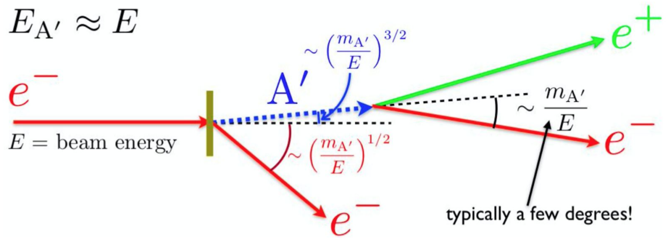
a) **secluded scenario**: provides no thermal target for accelerator- based experiments. Any ε value is allowed

b) **visible decay** scenario (although off-shell XX decay is allowed)

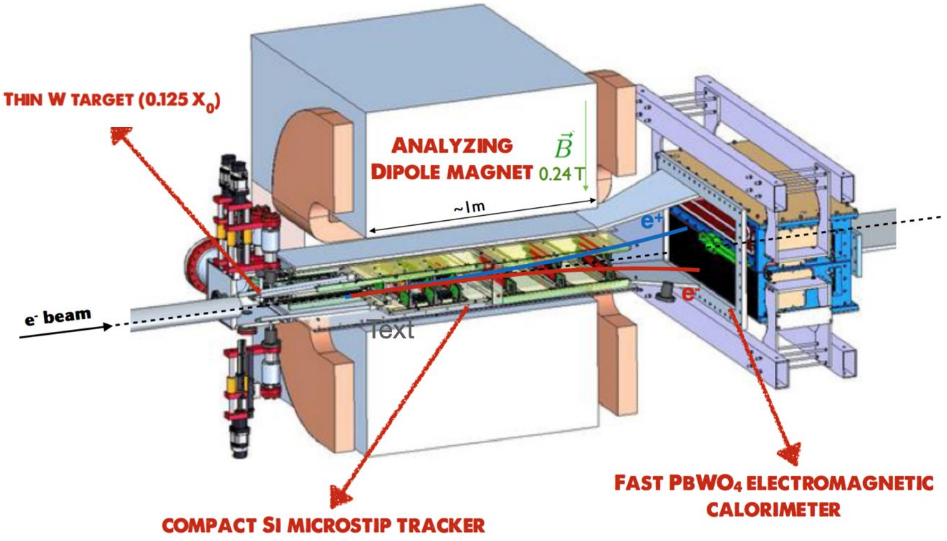
c) **invisible decay** scenario: A' decays to Dark Sector *invisible* particles

HPS: Heavy Photon Search

e- fixed target experiment installed in HALL B searching for dark photon visible decay



- CEBAF e- beam: energy (1.1-6.6 GeV) current (50nA-500nA)
- Thin W target : 10^{-3}X0
- Dipole magnet and 6-layers Si-tracker for momentum analysis and vertexing
- PbWO4 calorimeter for triggering and PID
- Signatures:
  - Resonant search
  - detached vertex search



HPS: Heavy Photon Search

PHYSICAL REVIEW D **98**, 091101(R) (2018)

Rapid Communications | Editors' Suggestion

Search for a dark photon in electroproduced e^+e^- pairs with the Heavy Photon Search experiment at JLab

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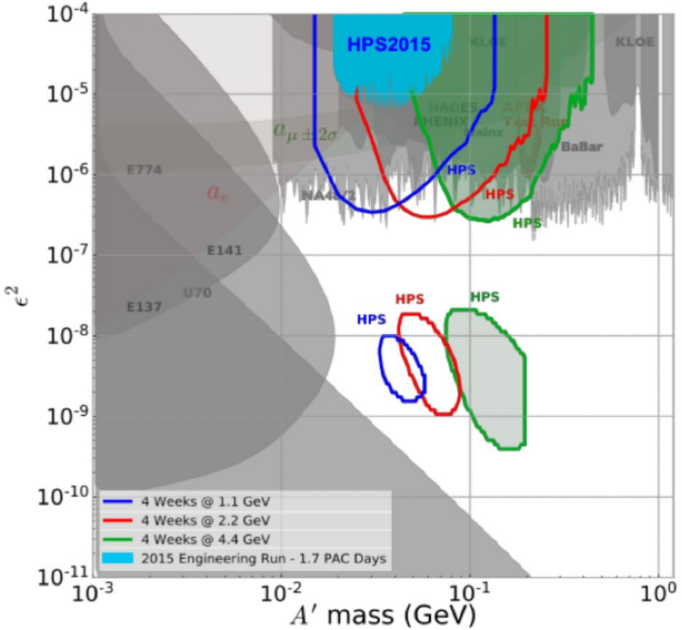
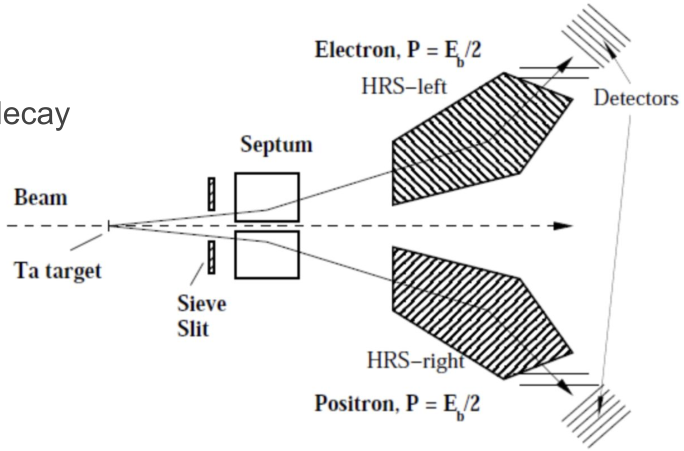
(Heavy Photon Search Collaboration)

- ❖ In 2014 approved by PAC41 for "high impact status". Beam time approved: 180 PAC days
- ❖ First engineering run in 2015. Results published in PRD rapid communication
- ❖ Many measurement campaign at different energy beam
  - ➢ 2015 Engineering run: Beam 1.05GeV @ 50nA on W target (~2 days)
  - ➢ 2016 Engineering run: Beam 2.3GeV @ 200nA on W target (~5days)
  - ➢ 2019 physics run: Beam 4.55 GeV @ 100nA on W target (~14 days)
  - ➢ 2021 physics run: Beam 3.74-1.92GeV @120-70nA on W target (~50 days)
- ❖ Collaboration busy with calibration and analysis of 2019 and 2021 data

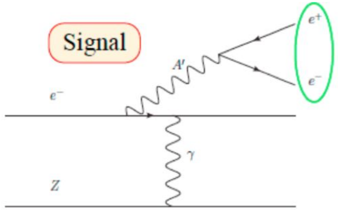


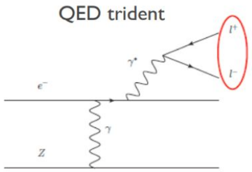
APEX: A-Prime EXperiment

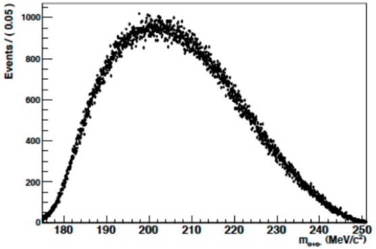
e- fixed target experiment installed in HALL A searching for dark photon visible decay

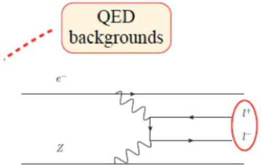


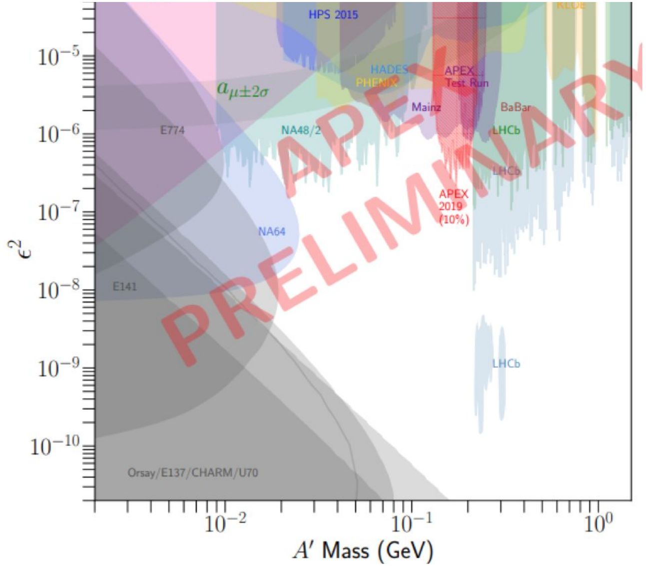
- ❖ Dark photon searched as a narrow resonance in e+e- mass over a smooth QED background
- ❖ Two High Resolution Spectrometers (HRSs) in coincidence to measure events with an e- in one arm and e+ in the other
- ❖ Standard HRS detector stack in both arms: Scintillators: S0 and S2(timing), VDC (tracking), Cherenkov and Calorimeters (PID)
- ❖ 2010 test run: beam 2.2GeV@150uA on tantalum foil
- ❖ Full run in 2019: accumulated over 100x statistics than test run







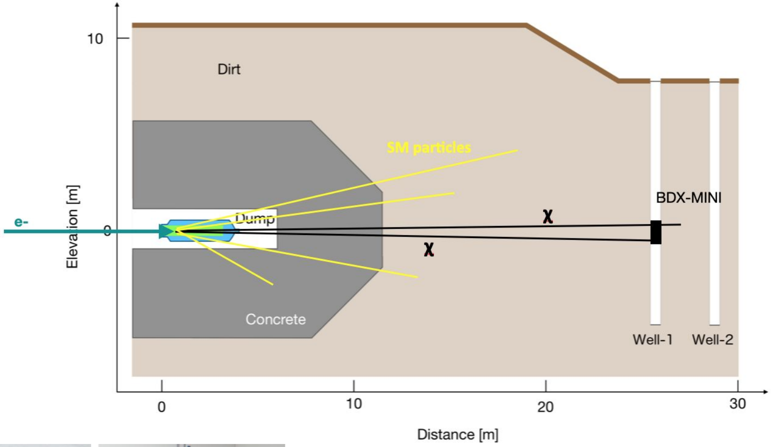


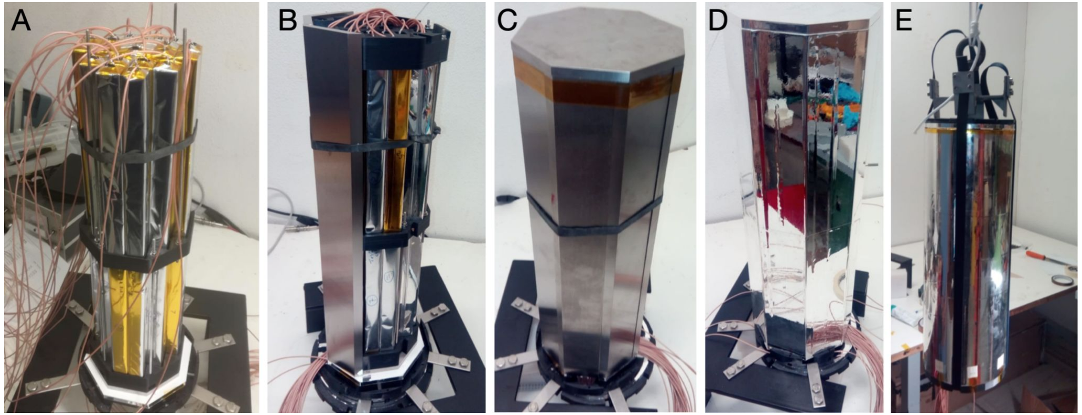


BDX-MINI: Beam Dump eXperiment - MINI

e- beam dump “pilot” experiment searching for LDM particles in the MeV-GeV mass range

- CEBAF 2 GeV e- beam (~150uA) impinging on Hall-A beam dump
- secondary beam of X particles produced through all previously discussed physics reactions
- Detector[1] placed in a pipe 25 m behind the dump
  - Compact PbWO4 detector (3.7×10^{-3} m^3)
  - Veto system: active (plastic scintillator) and passive (tungsten) layers
- X scattering on atomic e- through A’ exchange, recoil releasing energy O(100MeV)



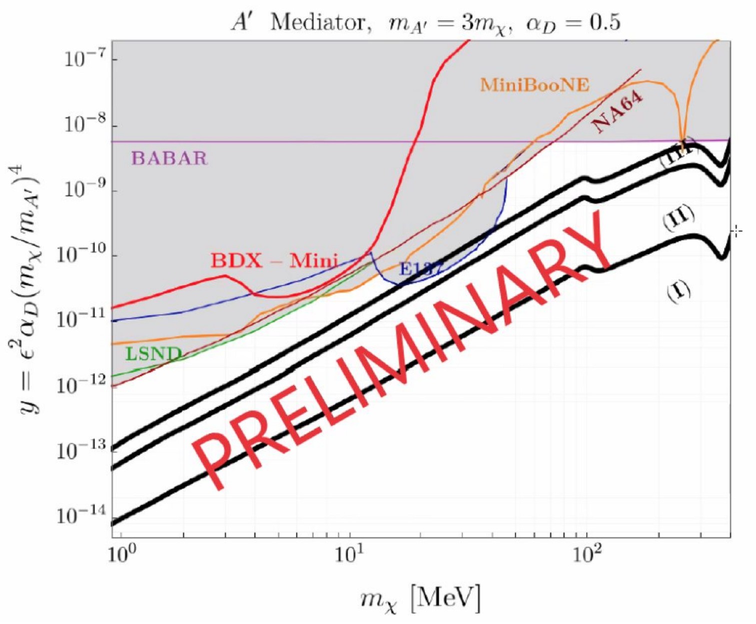


[1]M. Battaglieri et. al *Eur. Phys. J. C* ***81,*** *164 (2021).*

BDX-MINI: Beam Dump eXperiment - MINI

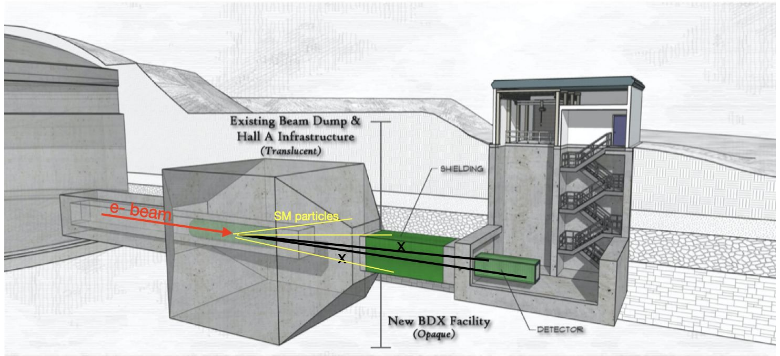
e- beam dump experiment searching for LDM particles in the MeV-GeV mass range

- ❖ Measurement took place in spring-summer 2020
  - ➢ collected ~$3x10^{21}$ EOT
  - ➢ beam energy: 2.2 GeV
  - ➢ beam current up to 150 uA
  - ➢ beam-on and beam-off measurements alternate (50% beam-on time)
    - ■ beam-off period used to estimate cosmic backgrounds
- ❖ Despite the reduced size, BDX-MINI exclusion limits comparable to previous experiment

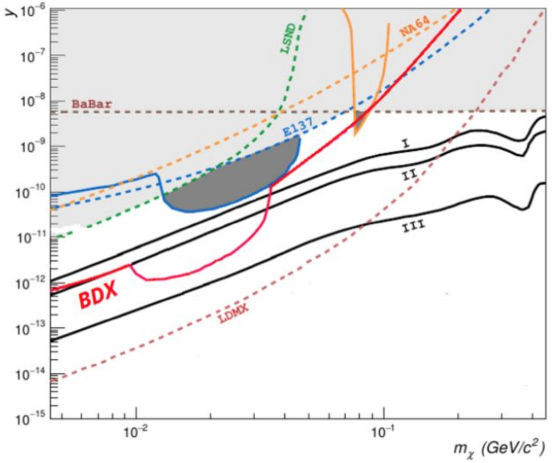


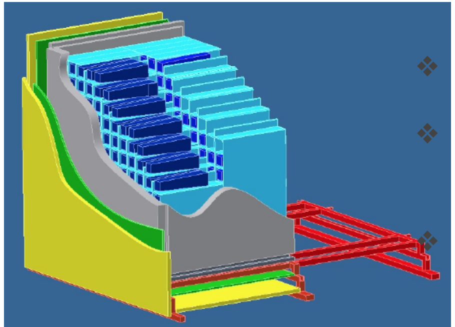
BDX: Beam Dump eXperiment

Natural evolution of BDX-mini: 11 GeV e- beam - **approved experiment at Jefferson Lab**



- **JLAB offers the best condition for BDX**
  - A high energy beam: 11 GeV
  - The highest available electron beam current: ~65uA (currently)
  - Charge : 10^22 EOT
  - Fully parasitic wrt Hall-A physics program
- **New facility to be built** 25m behid Hall-A beam dump
  - Passive shielding layer between beam dump and detector to reduce SM beam-related background
  - Sizeable overburden (~10 m water-equivalent) to reduce cosmogenic background
  - New underground hall (~8m) at 25 m downstream hall-A beam dump that will host the detector
- **Detector (1m3) with 2 components:** Ecal + Veto system





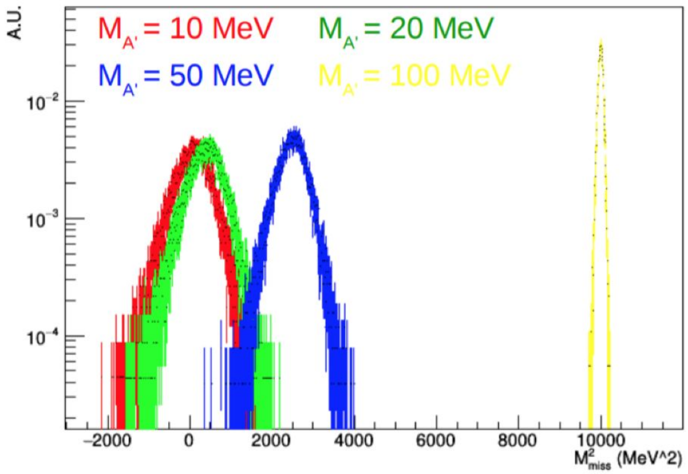
- ECal: CsI(Tl) crystals + SiPM
- Dual active-veto layer made of plastic scintillator counters +WLS+SiPM
- Passive lead layer surrounding ECAL

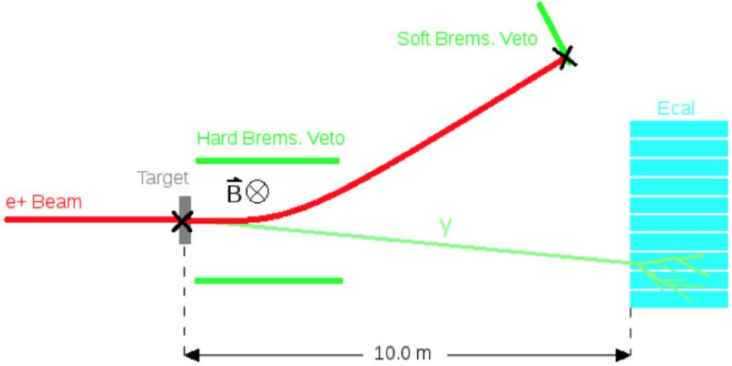
LDM searches with e+ beam: PADME-like approach

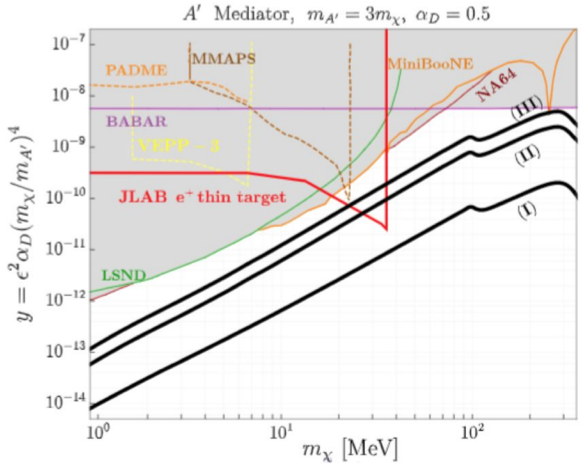
- 100 nA, 11 GeV e+ beam impinging on 100 um thin carbon target
- A' produced via e+e- -> γA' process
- outgoing photon measured in electromagnetic calorimeter and **missing mass** computed

$$M^2_{MISS} = (P_e + P - P_\gamma)^2$$

- **signal**: a peak in the missing mass distribution over a smooth SM background







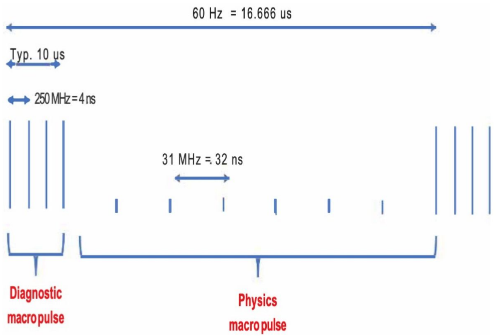
M. Battaglieri et al., Light dark matter searches with positrons *Eur. Phys. J. A* 57, 253 (2021)

LDM searches with e+ beam: thick target approach

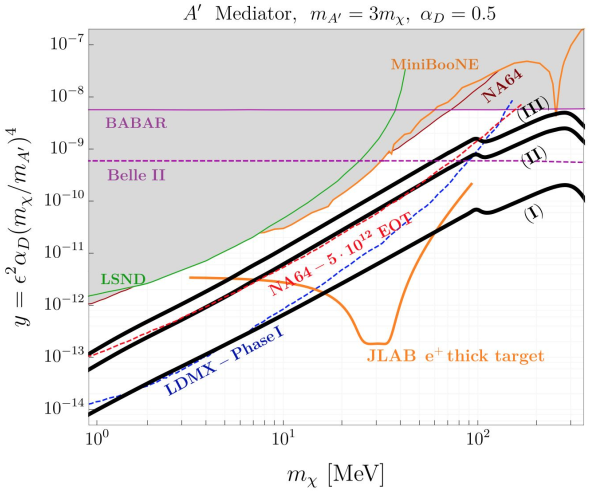
- **Missing energy** experiment with a 11 GeV positron beam
- e+ impinging on active thick target (ECAL): A' produced via resonant process e+e- -> A'
- large missing energy as LDM production signature

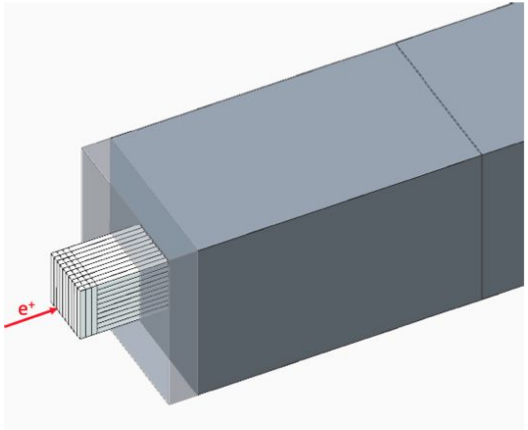
$$E_{miss} = E_{beam} - E_{ECAL}$$

- **Signal:** a peak in the missing energy distribution at a value depending solely on the dark photon mass
- HCAL to detect neutral particles escaping the ECAL mimicking signal



A non-trivial time structure of the beam is required to avoid e^+ beam pile-up in the detector.

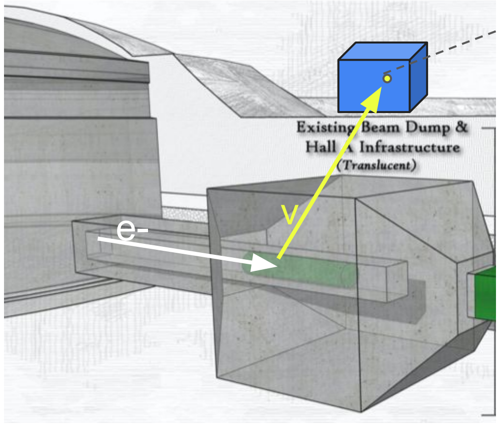


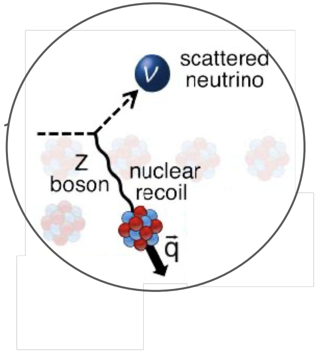


M. Battaglieri et al., Light dark matter searches with positrons *Eur. Phys. J. A* 57, 253 (2021)

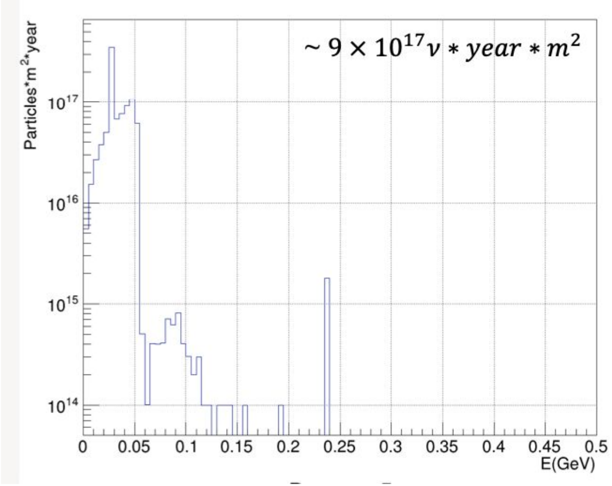
Secondary ν beam: CEνNS measurement

- ❖ A large flux of neutrinos is produced in the Hall-A beam-dump from π and μ decay
- ❖ Energy range ~few MeVs - O(100MeV)
- ❖ flux: 10^{18} ν/m^2 at ~ 10 m above the dump for 10^{22} EOT





- ❖ **Coherent Elastic ν-Nucleus Scattering**
  - ➢ The largest cross section among neutrino scattering channels for Eν < 100 MeV
  - ➢ Cross section is approximately proportional to N^2
  - ➢ Recoil energy transfer to the nucleus is O(10keV)
  - ➢ COHERENT has established the first detection of CEνSN
  - ➢ CEνSN provides info on: weak mixing angle, neutron radius of nuclei, non standard interactions (NSI) mediated by exotic particles



- ❖ **Possibility to run an CEνNS experiment at JLAB currently under study**

Conclusions

- Jefferson Lab features a rich BSM experimental program (HPS, APEX, BDX-MINI)
- New developments are expected in the nearby future: the Beam Dump eXperiment can run in the next few years provided the new hall is built
- The realization of a positron beam at JLAB paves the way to new competitive LDM experiments
- Secondary ν beam produced in the HALL-A dump can be exploited to explore “hot” physics scenario (CEνNS)