POKER
POsitron resonant annihilation into darK mattER

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European Research Council
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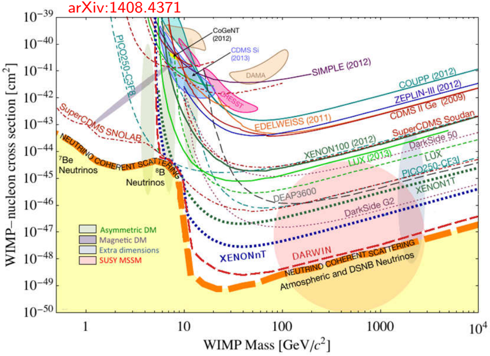
Outline

The dark sector - introduction

Dark matter: it is there, but very little is known about it! What is it? Where did it came from?

- The DM puzzle motivated a large number of experimental programs searching for DM from the galactic halo, exploiting different techniques.
- Intense experimental program searching for a signal in the multi-GeV mass region. So far, no positive evidences have been found.
- Where to look next?

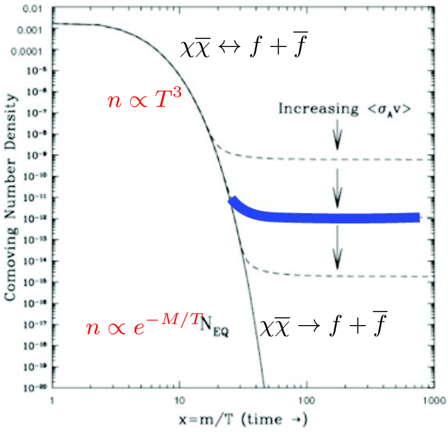


The dark sector - cosmological prior

Cosmological hypothesis: dark matter particles were in equilibrium with the primordial thermal bath in early Universe.
Reaction: $\chi\overline{\chi} \leftrightarrow f + \overline{f}$

Thermal history:

- Early Universe: high-T, relativistic regime. Both reactions ($\leftarrow$ and $\rightarrow$) were permitted
- As Universe expands and cools down ($T < m_\chi$), only the $\rightarrow$ reaction occurs. DM number density is exponentially suppressed: Boltzmann regime
- Eventually, DM particles can't find each other to annihilate further, thermal equilibrium breaks: **freeze-out**



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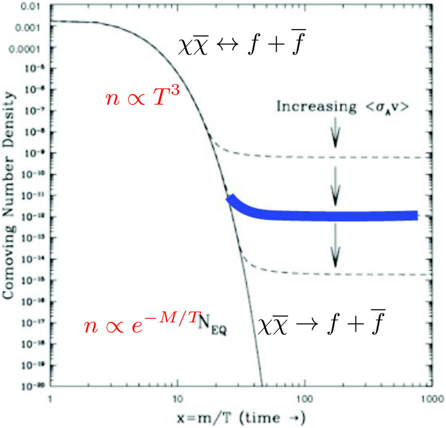
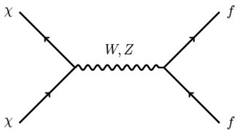
Thermal history:

- If annihilation cross section is too high (too small), DM particles would stay more (less) in equilibrium in the Boltzmann regime, resulting in a lower higher density at present time
- Observed relic abundance requires: $\langle\sigma v\rangle_{ann} \simeq 3 \cdot 10^{-26}$ cm^{-3}s^{-1}
- **This number corresponds to the scale of weak-force cross sections**



The dark sector - particle physics prior

WIMP miracle: weak-scale DM particle interacting with SM trough weak force reproduces the observed DM relic density today. If DM is made of WIMPs, no necessity for new interactions!
DM-SM interactions in the early Universe:



$$\langle \sigma v \rangle_{\text{WIMP}} \sim 3 \times 10^{-26} \text{cm}^3 \text{s}^{-1} \left(\frac{\text{TeV}}{m_\chi} \right)^2$$

Successful thermal freeze-out for weak scale-masses and cross sections

- Predicts direct-detection cross section
- Driven main experimental efforts so far in the DM field

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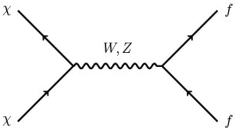

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Successful thermal freeze-out for weak scale-masses and cross sections

- Predicts direct-detection cross section
- Driven main experimental efforts so far in the DM field

So far, no clear positive observations in the DD field. Where to look next?

The dark sector - particle physics prior revisited

- WIMPs are natural DM candidates if DM has $\simeq O(1)$ coupling to SM through the EW force
- Sub-GeV scale arises if the coupling is $\ll 1 \rightarrow$ search for $<$ GeV scale **Light Dark Matter**

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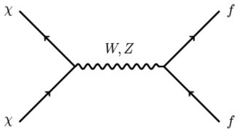
A light WIMP does not reproduce correct relic abundance:



$$\langle \sigma v \rangle_{\mathrm{WIMP}} \sim 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1} \left(\frac{\mathrm{TeV}}{m_\chi} \right)^2$$

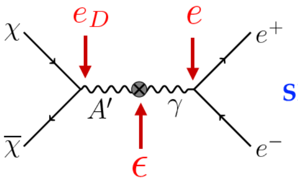
If $m_\chi \simeq 1$ GeV, $\langle \sigma v \rangle_{ann} \ll \langle \sigma v \rangle_{relic}$
A new SM-DM interaction mechanism is necessary.
Different mechanisms are possible - in the following, I'll focus on the so-called "dark-photon" hypothesis.

The dark sector - dark photon prior

DM-SM interactions:

$$\alpha_D \equiv \frac{e_D^2}{4\pi}$$

DM

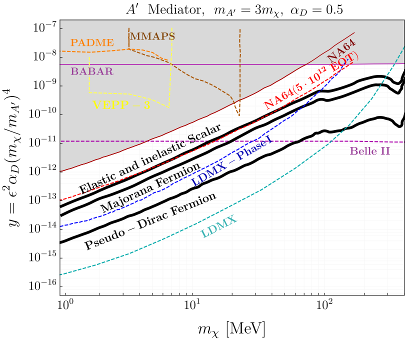


SM

$$\alpha \equiv \frac{e^2}{4\pi}$$

- Model parameters:
  - Dark photon and dark matter masses (sub-GeV)
  - $A' - \chi$ coupling $e_D \simeq 1$
  - $A' - SM$ coupling via kinetic mixing, $\varepsilon \ll 1$
- Annihilation cross section reads:

$$\langle \sigma v \rangle \propto \frac{\varepsilon^2 e_D^2 m_\chi^2}{m_{A'}^4} = \frac{\varepsilon^2 e_D^2 m_\chi^4}{m_{A'}^4} \frac{1}{m_\chi^2} \equiv \frac{y}{m_\chi^2}$$



For a given value of m_χ, thermal origin hypothesis imposes a unique value of y

Light dark matter

The light dark matter hypothesis can explain the (gravitationally) observed relic abundance, **provided a new interaction mechanism between SM and dark sector exists**[1]

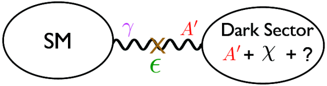
- Simplest possibility: "vector-portal". DM-SM interaction trough a new U(1) gauge-boson ("dark-photon") coupling to electric charge

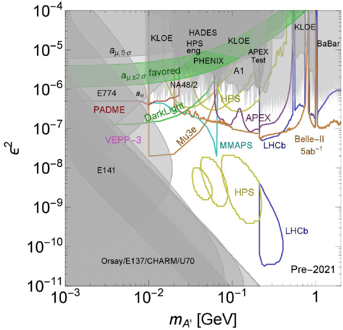
Model parameters:

- Dark-photon mass, M'_A and coupling to electric charge ε
- Dark matter mass, M_χ and coupling to dark photon, g_D ($\alpha_D \equiv g_D^2/4\pi$)

Experimental searches:

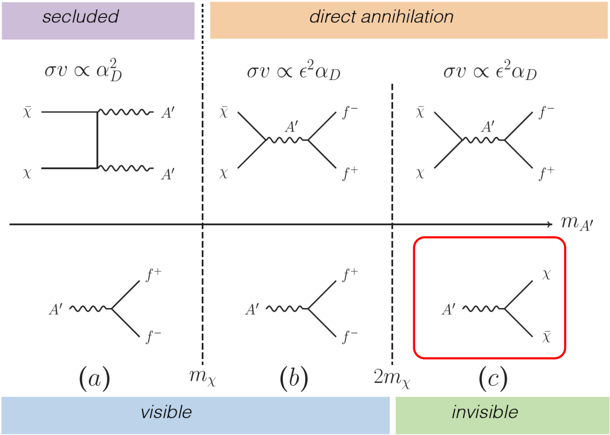
- A comprehensive LDM experimental program must investigate **both** the existence of χ particles and of dark photons
- A collection of complementary searches sensitive to all possible A' decays is required, visible & invisible





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

Light dark matter signatures



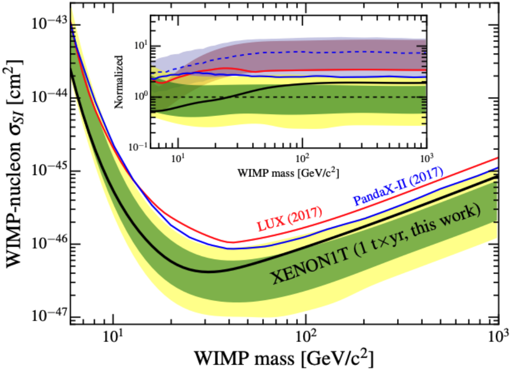
- (a) $m_{A'} < m_\chi$: **secluded** scenario. Provides no thermal target for accelerator-based experiments: **any** ε value is allowed
- (b) $m_\chi < m_{A'} < 2m_\chi$: **visible decay** scenario (although off-shell $\chi - \overline{\chi}$ production is allowed!)
- (c) $m_{A'} > 2m_\chi$: **invisible decay** scenario

Light dark matter searches at the intensity frontier

- Dark Matter direct detection experiments, typically optimized for $M_\chi \geq 1$ GeV, have a limited sensitivity in the sub-GeV range
  - $E_R \propto M_\chi^2/M_N$
  - Many ongoing efforts to overcome this limitation
- LDM-SM interaction cross section at low energy has a sizable dependence on the impinging particle velocity, with a drastic reduction for specific models

Latest Xenon1T WIMP results - 1805.12562

$E_R \gtrsim 5$ keV$_{NR}$, $M_N \simeq 122$ GeV



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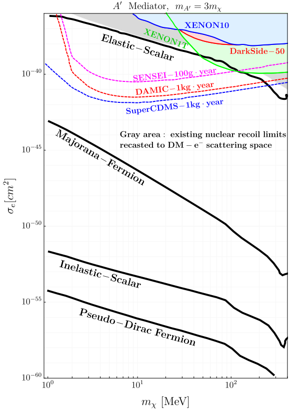

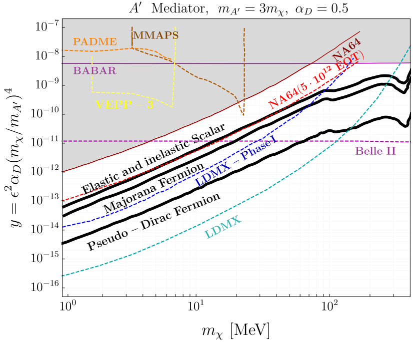

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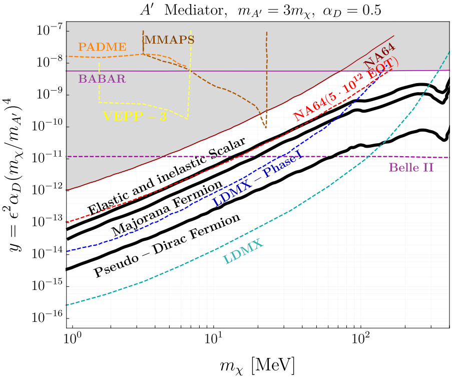
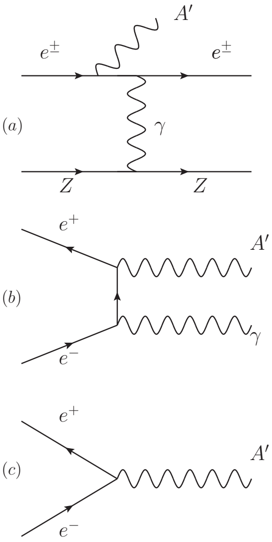


LDM at accelerators

Accelerator-based experiments at the *intensity* frontier are uniquely suited to explore the light dark matter hypothesis

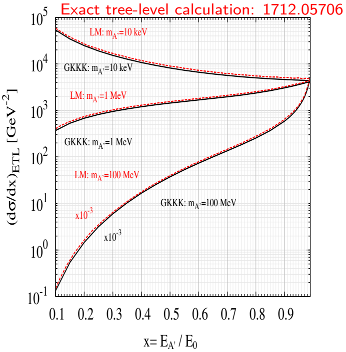
LDM production mechanisms with lepton beams

Three main LDM production mechanisms in fixed-target, lepton-beam experiments



a) A'-strahlung

- Radiative A' emission in nucleus EM field followed by $A' \to \chi\overline{\chi}$
- Scales as $Z^2\alpha_{EM}^3$
- Forward-boosted, high-energy A' emission



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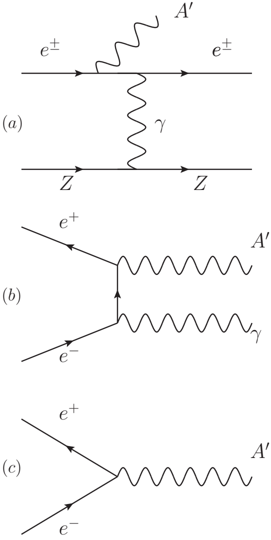
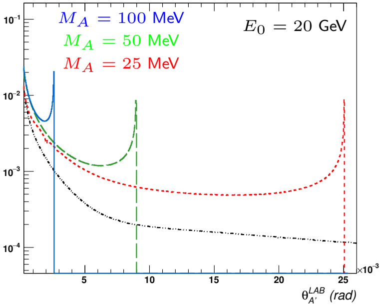


b) Non-resonant e^+e^- annihilation

- $e^+e^- \rightarrow A'\gamma$ followed by $A' \rightarrow \chi\overline{\chi}$
- Scales as $Z\alpha_{EM}^2$
- Forward-backward emission, $E_{A'}^{AVG} = \frac{E_0}{2}(1 + \frac{M_A^2}{2m_e E_0})$



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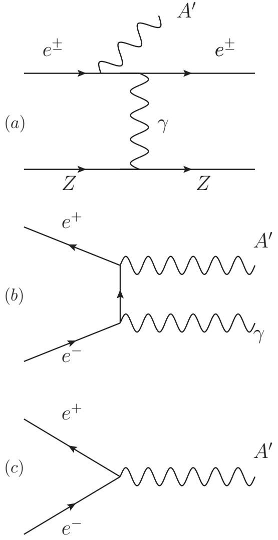
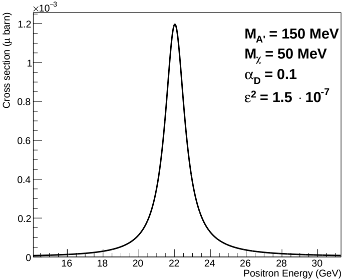


c) Resonant e^+e^- annihilation

- $e^+e^- \to A' \to \chi\overline{\chi}$
- Scales as $Z\alpha_{EM}$
- Closed kinematics: $P_\chi + P_{\overline{\chi}} \simeq P_{e+}$
- Resonant, Breit-Wigner like cross section with $M_{A'} = \sqrt{2m_e E}$

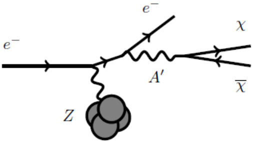


Fixed *passive* thick-target LDM searches: *electron* beam-dumps

Beam dump experiments: LDM direct detection in a e^- beam, fixed-target setup[2]

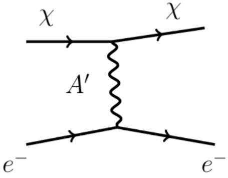
χ production

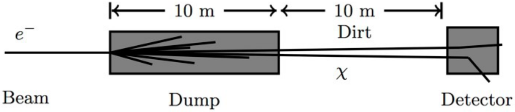
- High-energy, high-intensity e^- beam impinging on a thick target
- Secondary χ particles beam produced through **all** previously discussed physics reactions



χ detection

- Detector placed behind the dump, O(10-100) m
- Neutral-current χ scattering trough A' exchange, recoil releasing visible energy
- Different signals depending on the interaction (most promising channel: $\chi - e^-$ elastic scattering)





[2] For a comprehensive introduction: E. Izaguirre *et al*, Phys. Rev. D 88, 114015

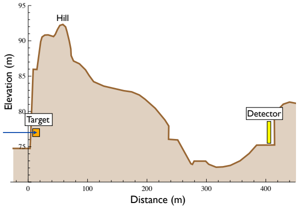
E137 at SLAC

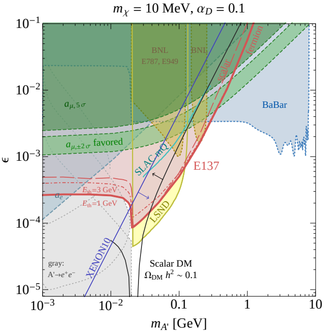
ALPs search experiment, results re-interpreted as LDM search.

- **Beam:** 20-GeV e^- beam, $\simeq 2 \cdot 10^{20}$ EOT
- **Target:** Water-filled Al beam dump
- **Shielding:** 179 m of ground (hill)
- **Decay:** 204 m of open air
- **Detector:** 8-X_0 EM calorimeter + MWPC

Different production mechanisms have been considered:

- First analysis focused on A'-strahlung production mechanism (Phys. Rev. Lett. 113, 171802 (2014))
- New analysis focused on secondary *positrons*: new resonant production mechanism $e^+e^- \to \chi\overline{\chi}$ (Phys. Rev. Lett. 121, 041802 (2018))





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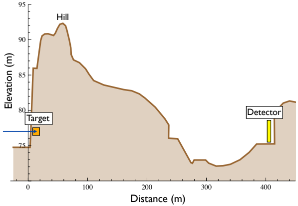
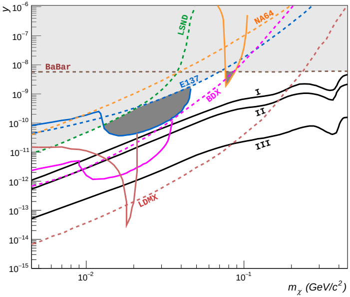




BDX: Beam Dump eXperiment

Modern beam-dump experiment at JLab: 11-GeV e^- beam, Al/H_2O beam-dump

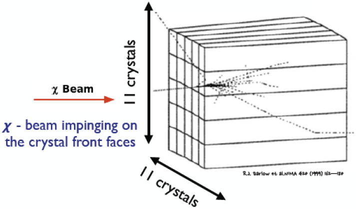
Experimental setup

- Detector installed O(20 m) behind Hall-A beam dump, in a new experimental hall
- Passive shielding layer between beam dump and detector to reduce SM beam-related background
- Sizable overburden ($\simeq$ 10 m water-equivalent) to reduce cosmogenic background

Detector design

- EM calorimeter: CsI(Tl) crystals+SiPM readout
- Two plastic-scintillator -veto layers
- Passive lead layer between inner and outer veto

Total active volume: $\simeq$ 0.5 m^3



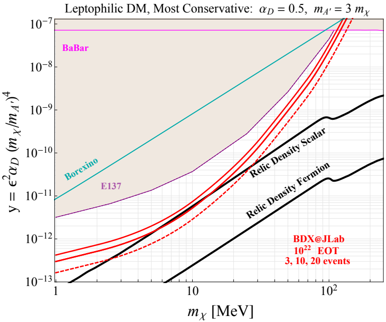
BDX: reach and status

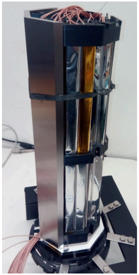
BDX reach:

- With $\mathrm{O}(10^{22})$ EOT, BDX can explore an unique region in the MeV-GeV LDM mass region, with a discovery potential up to two orders of magnitude better than existing or planned experiments
- Final reach is limited by the beam-related irreducible ν background

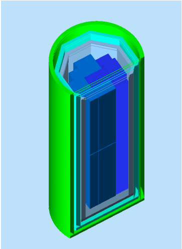
Experiment status:

- Experiment approved by JLab PAC in 2018 with the highest scientific rating
- Completed test run with small-scale prototype (BDX-MINI), results expected by the end of 2021
- Currently securing fundings to build experimental infrastructure and detector





BDX-Mini Geant4 implementation

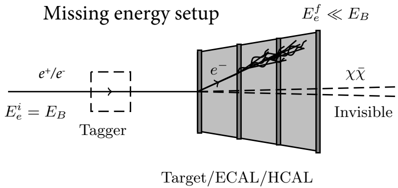


Fixed *active* thick-target LDM searches: missing energy experiments

Beam-dump experiments pay a penalty $N_S \propto \varepsilon^4$ in the event yield:
production $\times$ detection
New approach: missing energy measurement - the *active thick target* is the detector, $N_S \propto \varepsilon^2$

Missing Energy Experiments

- Specific beam structure: impinging particles impinging "one at time" on the active target
- Deposited energy E_{dep} measured event-by-event
- Signal: events with large $E_{miss} = E_B - E_{dep}$
- Backgrounds: events with ν / long-lived (K_L) / highly penetrating (μ) escaping the detector

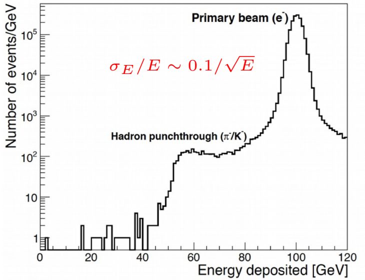


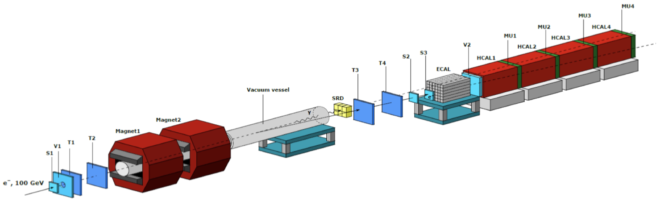
NA64

Missing energy experiment at CERN North Area, 100 GeV e^- beam[3]

Experiment Setup

- EM-Calorimeter: $40X_0$, Pb/Sc Shashlik
- Hadron calorimeter: 4 m, 30 λ_I
- Beam identification system: SRD + MM trackers
- Plastic scintillator based scintillator counters for VETO





3 Phys.Rev.Lett. 123 (2019) 121801

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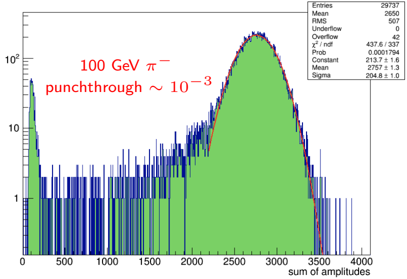

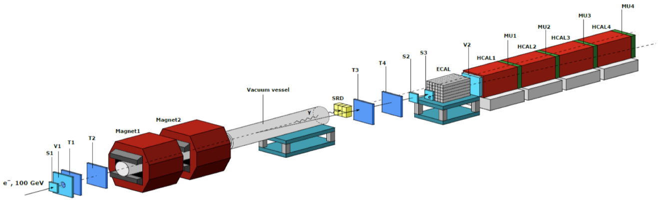

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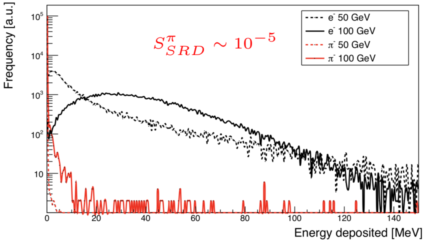
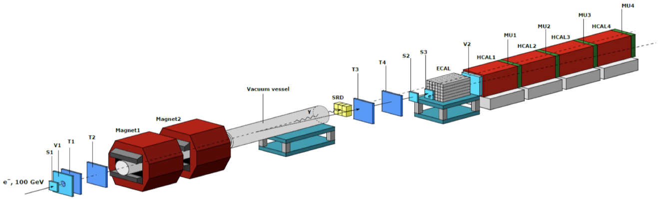




[3] Phys.Rev.Lett. 123 (2019) 121801

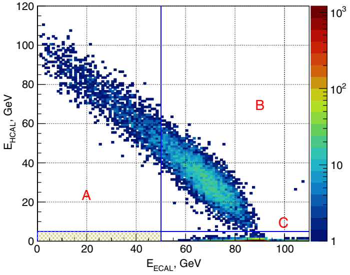
NA64

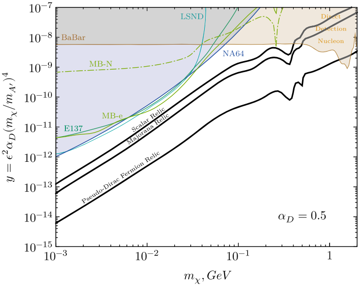
Latest results

- NA64 results based on $2.84 \cdot 10^{11}$ EOT
- After applying all selection cuts, no events are observed in the signal region $E_{ECAL} < 50$ GeV, $E_{HCAL} < 1$ GeV
- Expected number of background events $\sim$ 0.5 compatible with null observation
- **Most competitive exclusion limits** in large portion of the LDM parameters space

TABLE I: Expected background for 2.84×10^{11} EOT.

Background source	Background number, n_b
punchthrough γ's, cracks, holes	< 0.01
loss of dimuons	0.024 ± 0.007
$\mu \to e\nu\nu$, π, $K \to e\nu$, K_{e3} decays	0.02 ± 0.01
e^- interactions in the beam line	0.43 ± 0.16
μ, π, K interactions in the target	0.044 ± 0.014
accidental SR tag and μ, π, K decays	< 0.01
Total n_b	0.53 ± 0.17





POKER: **PO**sitron resonant annihilation into dar**K** matt**ER**

A missing-energy, active thick-target, light dark matter search with positrons

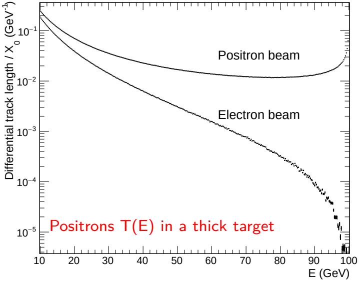
Why positrons?

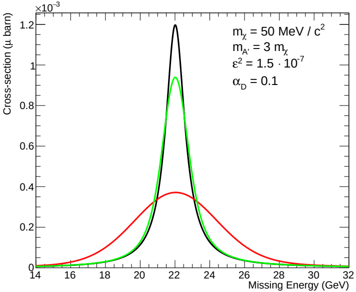
Signal production reaction: $e^+e^- \to A' \to \chi\overline{\chi}$

- Large event yield: $N_s^{annihil} \propto Z\alpha_{EM}$ vs $N_s^{brem} \propto Z^2\alpha_{EM}^3$
- Missing energy distribution shows a **peak** around $E_R = \frac{M_{A'}^2}{2m_e}$

Project goal

- Demonstrate the technique and set the basis of the first optimized light dark matter search at a positron-beam facility
  - Design, construct, and run pilot experiment
- Study all the physics cases accessibile with the new methodology





POKER

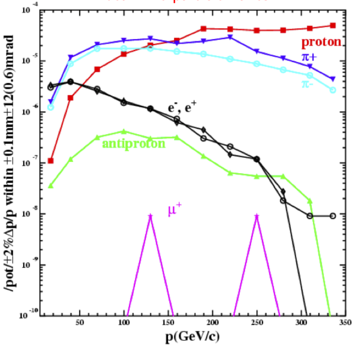
Key POKER elements

- Beam: high energy, 1 e^+ "at time" impinging on the detector
  $\rightarrow$ H4 beamline at CERN
- Active target: enhanced energy resolution to exploit the missing energy kinematic signature
- Hermetic veto system to reject backgrounds

POKER strategy:

- **Beam:** exploit the H4 beamline at CERN and the NA64 beam tagging and diagnostic devices
  - H4 beam: 100 GeV e^+ with $1e^+/\mu s$, $\approx 10^{10}$ e^+ot/day
- **Veto:** re-use the existing NA64 hadronic calorimeter
- **Active target:** design and construct an optimized, high-resolution EM calorimeter

H4 beamline particle fluxes



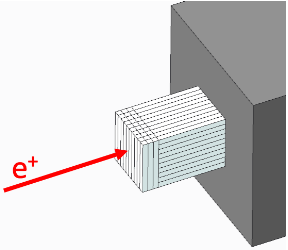
POKER active target

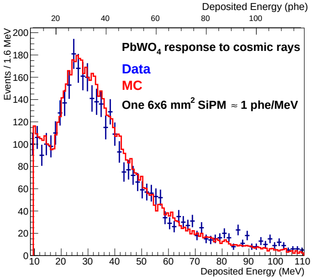
Preliminary design: $35X_0$ $PbWO_4$ calorimeter with SiPM readout

- 10x10 matrix of 20x20x250 mm^3 crystals + 3 layers in front
  - Absorb high-energy γ produced by Bremmstrahlung in first few X_0 at level $10^{-13}/e^+$ot
  - Avoid transverse energy leakage
- Required $\sigma_E/E \sim 2\%/\sqrt{E}$
  - $LY \sim 2.5\,\mathrm{phe}/MeV$
  - Use four 6x6 mm^2 SiPMs, 25 μm cell coupled to each crystal

Radiation levels are critical

- EM dose up to 200 rad/h (CMS ECAL max: 500 rad/h)
  - Light-induced radiation damage annealing
  - Beam-spot rastering
- $\phi_n \leq 10^4$ n$_{eq}$ cm^{-2}s^{-1}: no effects expected





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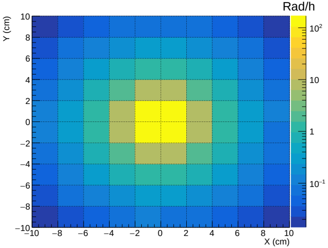
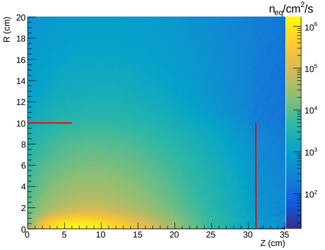
Radiation dose from 100 GeV e^+ at 1 MHz



Neutrons flux from 100 GeV e^+ at 1 MHz



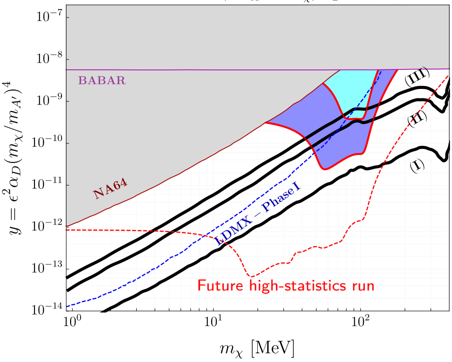
POKER sensitivity to LDM

Pilot measurement at the H4 beamline with 100 GeV e^+ beam

- **Baseline scenario:** $5 \cdot 10^{10}$ e^+ot, 50 GeV missing energy threshold
- **Aggressive scenario:** $3 \cdot 10^{11}$ e^+ot, 25 GeV missing energy threshold
- Future experimental program with multiple 10^{13} e^+ot runs at different energies

The pilot run will also assess the POKER sensitivity to further physics cases

- Visible-decaying A'
- Strongly Interacting Massive Particles



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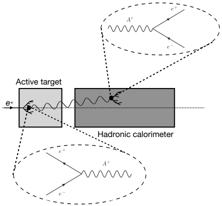

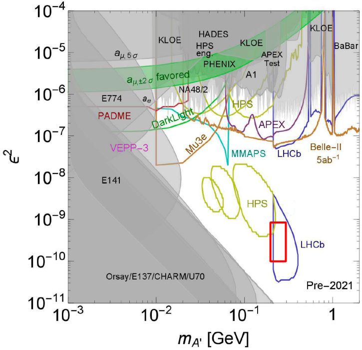

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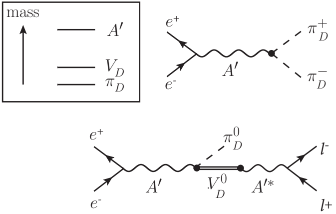
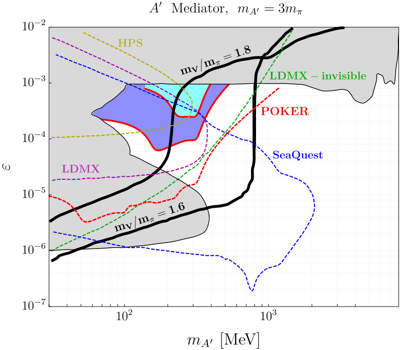


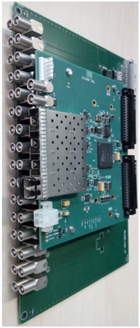


POKER test run

Measure 100 GeV e^+ at $\simeq$ 1 MHz rate: demanding conditions for DAQ and trigger

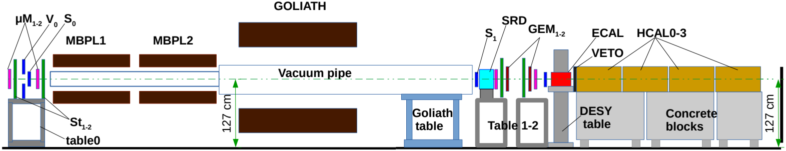
- **Trigger:** Identify impinging e^+ by coincidence between scintillators installed on the beam line and *minimal* energy deposition in ECAL
  - No sensitivity to *extreme* cases with $E_{miss} = E_{beam}$
- **DAQ:** Reduce rate to disk with online cut on E_{dep}, prescale FEE$^+$ by factor $\simeq 100$
  - Online calibrations and monitoring are critical
  - Same strategy adopted by NA64

NA64 DAQ board



SIDE VIEW

From NA64 2018 SPSC report



POKER project development

5-years ERC project started in December 2020

- Four working packages:

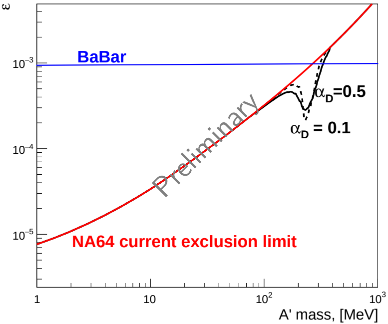
Working package	Year-1	Year-2	Year-3	Year-4	Year-5
a) Signal and backgrounds characterization					
b) Experiment design					
c) Detector construction and commissioning					
d) Pilot run data-taking and analysis					

- Pilot run measurement expected in 2024, matched to LHC injectors schedule

POKER and NA64

- POKER was presented to the NA64 collaboration before submitting the ERC proposal, with very positive feedback.
- The POKER team is now officially joining the NA64 collaboration.
- A first, preliminary e^+ beam data taking run will be completed in Summer 2021 with the current setup to characterize beam impurities.

A re-evaluation of the existing NA64 exclusion limit from the 2016-2017-2018 e^- dataset, accounting for the e^+e^- annihilation channel, is currently in progress.



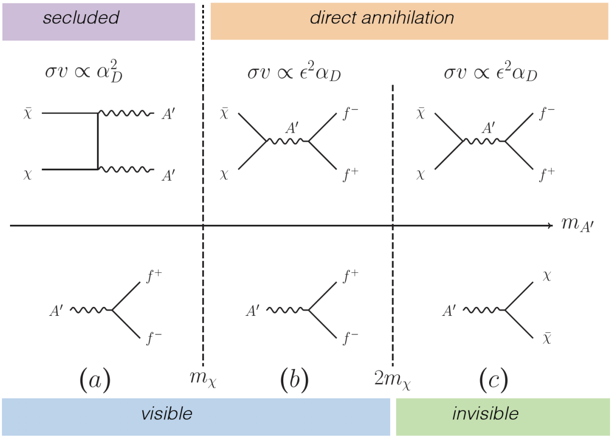
Conclusions

- Light dark matter scenario (MeV-to-GeV range) is largely unexplored
  - Can efficiently explain DM relic density
  - Theoretically founded as the "traditional" DM paradigm, assuming a **new** DM-SM interaction mechanics, exists
  - Accelerator-based experiments at the *intensity frontier* are uniquely suited to explore it
- **POKER: PO**sitron resonant annihilation into dar**K** matt**ER**
  - Missing-energy active thick-target search with high-energy positrons
  - Exploit resonant LDM production: high signal yield and unique kinematic signature
- **Goal:** perform a pilot run experiment at CERN H4 beamline (100 GeV e^+ beam)
  - Use a new high-resolution $PbWO_4$ calorimeter and exploit existing NA64 beam diagnostic and hadronic calorimeter devices
  - Accumulate at least $5 \cdot 10^{10}$ e^+ot

New collaborators are welcome!!!

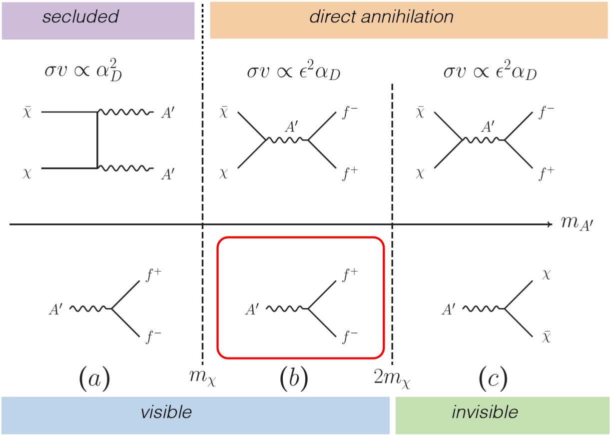
Backup slides

Light dark matter signatures



- (a) $m_{A'} < m_\chi$: **secluded** scenario. Provides no thermal target for accelerator-based experiments: **any** ε value is allowed.
- (b) $m_\chi < m_{A'} < 2m_\chi$: **visible decay** scenario (although off-shell $\chi - \overline{\chi}$ production is allowed!)
- (c) $m_{A'} > 2m_\chi$: **invisible decay** scenario.

Light dark matter signatures



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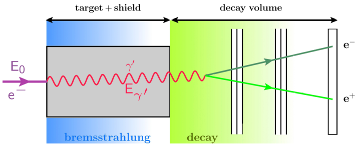
- (c) $m_{A'} > 2m_\chi$: **invisible decay** scenario.

A' production and visible decay detection in a fixed thick-target setup

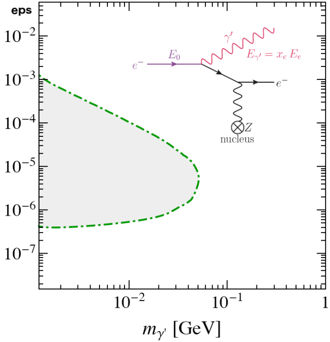
Reaction topology:

- A' production: radiative A' emission
  $e^- N \to e^- N A'$
- A' propagation: for low ε values ($\lesssim 10^{-5}$) the A' is long-lived, resulting to a detached decay vertex.
- A' detection: measurement of the $e^+\ e^-$ decay pair in a downstream detector.



Number of events:
Dependence on main parameters[4]:

$$N \sim N_{eot} n_{sh} \int dE' dE_e dt I_e(E_e,t) \frac{d\sigma}{dE'} e^{-L_{sh}/\lambda}(1 - e^{-L_d/\lambda})$$



- Upper bound:
  $N_{evt} \propto \varepsilon^2 e^{-L_{sh}/l_{A'}}$, $l_{A'} \propto E_0/\varepsilon^2$
- Lower bound:
  $N_{evt} \propto \varepsilon^2 L_d/l_{A'} \propto \varepsilon^4$

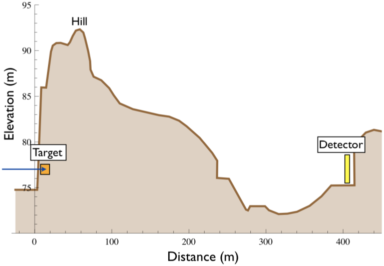
[4] For a review: S. Andreas, Phys.Rev. D86 (2012) 095019

E137 at SLAC

Experiment originally proposed for ALPs search, results re-interpreted as a visible A' search.

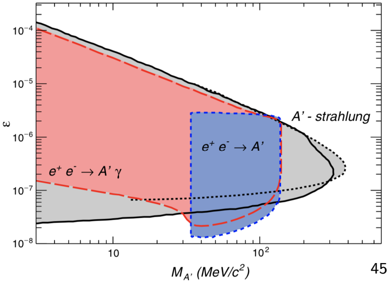
Experiment Parameters:

- **Beam:** 20-GeV e^- beam, $\simeq 2 \cdot 10^{20}$ EOT
- **Target:** Water-filled Al beam dump
- **Shielding:** 179 m of ground (hill)
- **Decay:** 204 m of open air
- **Detector:** 8-X_0 EM calorimeter + MWPC

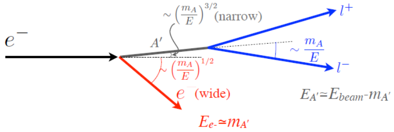


Results:

- Experiment observed 0 events, exclusion limits at 90% CL $= 2.3$ signal events.
- Two re-analysis with different approximations (Miller, Andreas) resulting in a similar exclusion limit.
- Recent limits extension (Marsicano) considering secondary positrons annihilation on atomic e^-

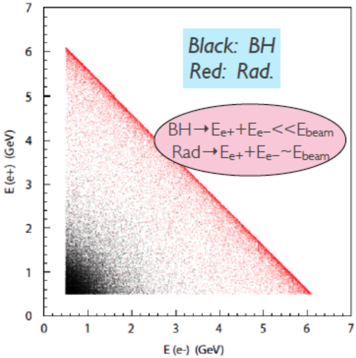


A' production and visible decay detection in a fixed thin-target setup



Radiative production mechanism:
$e^- N \to e^- N A' \to e^- N e^+ e^-$, $e^+ e^-$ pairs detected through a downstream particle spectrometer.
Two detection strategies:

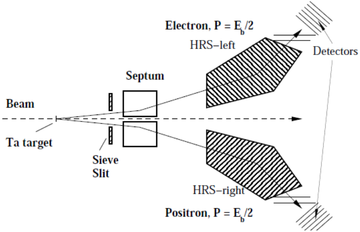
- High ε: **resonance search**, look for a "bump" in the $M_{e^+e^-}$ spectrum over the continuos QED background
- Low ε: **detached-vertex search**



JLab Hall-A experiment[5]: two-arms spectrometers resonance search ("bump-hunting") for $50 - 500$ MeV A' decaying promptly to e^+e^-.

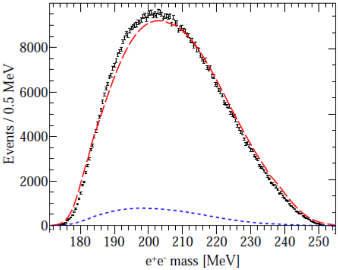
Setup:

- 2.26 GeV, 150 μA e^- beam impinging on a thin Ta target.
- e^+e^- detection: Hall-A HRS
  - Momentum reconstruction: drift chambers
  - Triggering and PID: Cerenkov and scintillator counters
  - Central momenta: 1.131 GeV. Momentum acceptance: $\pm 4.5\%$.



Data selection (2010 test run):

- Tight time coincidence between two spectrometers
- Track-quality cut / energy sum cut
- **Final data set:** 770k e^+e^- events, O(7.5%) accidentals contamination. Mass resolution: 0.85÷1.11 MeV



[5] Phys. Rev. Lett. **107** (2011) 191804

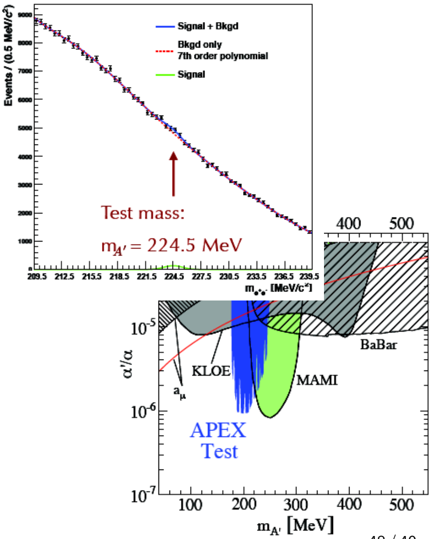
APEX 2010 test run: no signals were observed. Exclusion limits were set for $m'_A = 178 \ldots 250$ MeV, $\varepsilon^2 > 10^{-6}$.

Analysis: search for a small, narrow resonance over a smooth background

- Multiple fits to mass spectrum in narrow windows (30.5 MeV): signal (gaussian) + background (7^{th} order pol.)
- Extract local and global $p-$value trough Likelihood-ratio test
- Determine 2σ exclusion limit on ε

Status - future plans:

- Test run results published in PRL
- Full experiment just completed (Fall 2019):
  - Run with several energies and spectrometer settings
  - Multi-foil Ta-target to enhance acceptance at large m'_A values

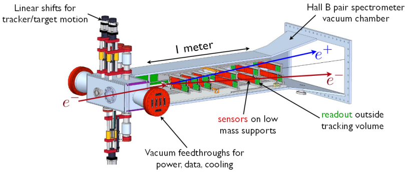


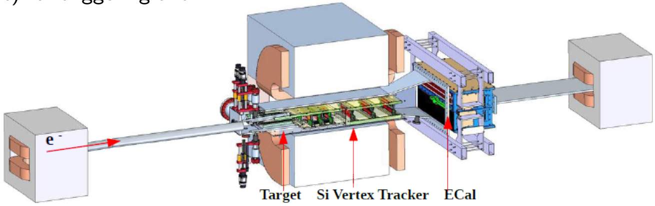
HPS: setup

HPS experiment in Hall-B: fixed-target A' search, with two complementary approaches, “bump-hunting” and “detached vertexing”.

Setup: compact forward spectrometer matched to the A' kinematics

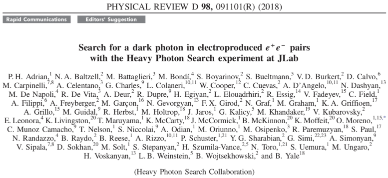
- Detector mounted in Hall-B “alcohove”, behind CLAS12
- Thin W target ($\simeq 10^{-3} X_0$)
- Dipole magnet and 6-layers Si-tracker for momentum analysis and vertexing
- $PbWO_4$ calorimeter (442 crystals, APD readout) for triggering and PID





HPS: results and status

- July 2012: HPS demonstrated the feasibility of the measurement and the operation of the detector in a test run[3]
- Spring 2015: 1.7 PAC days @ 1.06 GeV. Results published in PRD rapid communications[4]
- Spring 2016: 5 PAC days @ 2.3 GeV. Results expected next few months
- Summer 2019: 2 months running @ 4.55 GeV - $\simeq 10^5$ nbarn^{-1} accumulated.



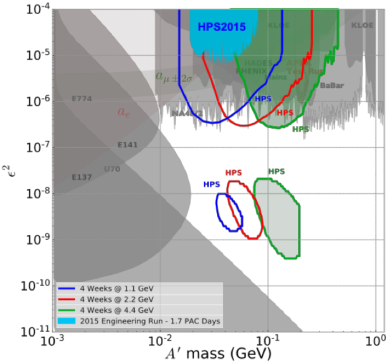
PHYSICAL REVIEW D **98,** 091101(R) (2018)

Rapid Communications | Editors' Suggestion

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

P. H. Adrian,[1] N. A. Baltzell,[2] M. Battaglieri,[3] M. Bondí,[4] S. Boyarinov,[2] S. Bueltmann,[5] V. D. Burkert,[2] D. Calvo,[6] M. Carpinelli,[7,8] A. Celentano,[3] G. Charles,[9] L. Colaneri,[10,11] W. Cooper,[12] C. Cuevas,[2] A. D'Angelo,[10,11] N. Dashyan,[13] M. De Napoli,[4] R. De Vita,[3] A. Deur,[2] R. Dupre,[9] H. Egiyan,[2] L. Elouadrhiri,[2] R. Essig,[14] V. Fadeyev,[15] C. Field,[1] A. Filippi,[6] A. Freyberger,[2] M. Garçon,[16] N. Gevorgyan,[13] F. X. Girod,[2] N. Graf,[1] M. Graham,[1] K. A. Griffioen,[17] A. Grillo,[15] M. Guidal,[9] R. Herbst,[1] M. Holtrop,[18] J. Jaros,[1] G. Kalicy,[5] M. Khandaker,[19] V. Kubarovsky,[2] E. Leonora,[4] K. Livingston,[20] T. Maruyama,[1] K. McCarty,[18] J. McCormick,[1] B. McKinnon,[20] K. Moffeit,[20] O. Moreno,[1,15,*] C. Munoz Camacho,[9] T. Nelson,[1] S. Niccolai,[9] A. Odian,[1] M. Oriunno,[1] M. Osipenko,[3] R. Paremuzyan,[18] S. Paul,[17] N. Randazzo,[4] B. Raydo,[2] B. Reese,[1] A. Rizzo,[10,11] P. Schuster,[1,21] Y. G. Sharabian,[2] G. Simi,[22,23] A. Simonyan,[9] V. Sipala,[7,8] D. Sokhan,[20] M. Solt,[1] S. Stepanyan,[2] H. Szumila-Vance,[2,5] N. Toro,[1,21] S. Uemura,[1] M. Ungaro,[2] H. Voskanyan,[13] L. B. Weinstein,[5] B. Wojtsekhowski,[2] and B. Yale[18]

(Heavy Photon Search Collaboration)



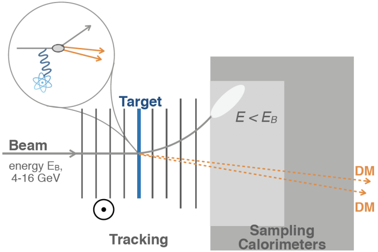
[3] Nucl. Instrum. Meth. A **777** (2015) 91

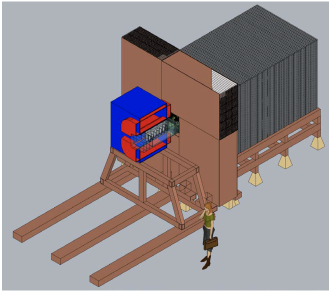
[4] Phys. Rev. D 98, 091101 (2018)

LDMX

Missing *momentum* experiment with multi-GeV electron beam[6]
Goal: 10^{16} EOT in few years $\sim 1e^{-}/10$ ns!
Very challenging detector design

- **Fast Si tracker**
  - Tagging tracker in 1.5 T field
  - Recoil tracker in fringe field
  - W (0.1-0.3 X_0) target in between
- **EM Calorimeter**
  - Design based on ongoing CMS forward Si/W calorimeter upgrade
- **Hadron Calorimeter**
  - Veto for penetrating hadrons (most critical: neutrons)
  - Sci/steel sampling design
  - Hermetic: surrounds ECAL on back and on sides



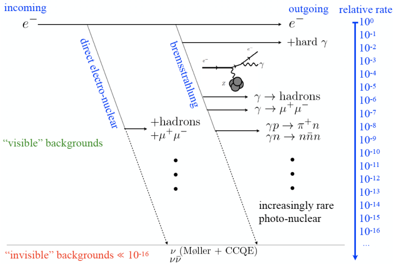


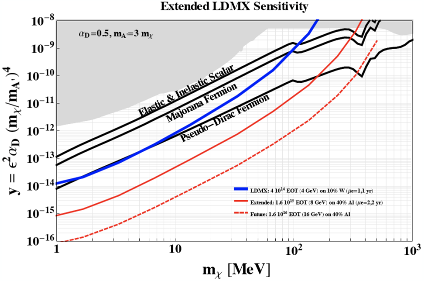
[6] Baseline design paper: arXiv:1808.05219

LDMX

On-going backgrounds study and detector design effort

- Close to 0 background target for pilot run - 10^{14} EOT
  - Particular care for non-trivial hadronic backgrounds (e.g. n pairs, backward particles, . . .)
- Large statistics run optimization: p_T signature / HCAL design / beam energy



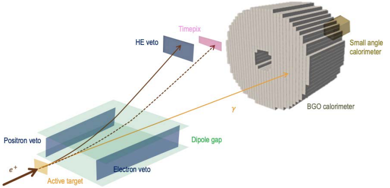


Missing mass searches

Positron beam impinging on a **thin target**: mono-photon missing mass resonance search in the reaction $e^+e^- \to A'\gamma$. Limiting factor: $M_{A'} < \sqrt{2m_e E_{e^+}}$

The PADME experiment at LNF-BTF:

- 550 MeV e^+ beam, 50 Hz rep. rate.
  - $M_{A'}$ max: 23.7 MeV
- 100 μm C *active* target to monitor beam-spot position
- BGO calorimeter, 616 crystals
- First 2019 run: $7.4 \cdot 10^{12}$ e^+ot
- Ongoing 2020 run



Other proposals:

- VEPP3: $E_{e^+} = 500$ MeV, 10^{16} e^+ot/y
- Cornell: $E_{e^+} = 5.3$ GeV, 10^{18} e^+ot/y
- JLAB: $E_{e^+} = 11$ GeV, 10^{19} e^+ot/y