

POKER

POsitron resonant annihilation into dark mattER

Andrea Celentano

INFN-Genova



Outline

- 1 Introduction
- 2 Light Dark Matter searches at the intensity frontier
 - LDM production mechanisms with lepton beams
 - E137/BDX
 - NA64
- 3 The POKER project
- 4 Conclusions

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

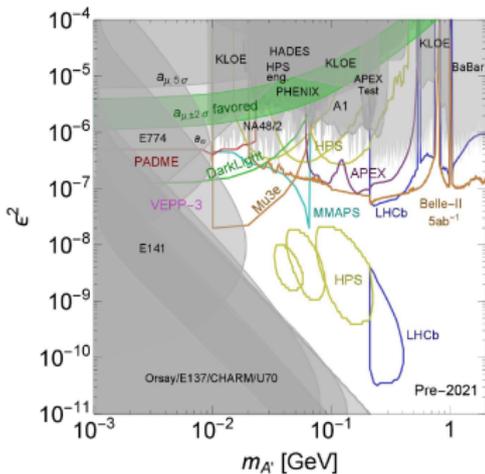
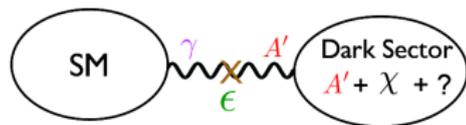
- Simplest possibility: “vector-portal”. DM-SM interaction through a new U(1) gauge-boson (“dark-photon”) coupling to electric charge

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 ($\alpha_D \equiv g_D^2/4\pi$)

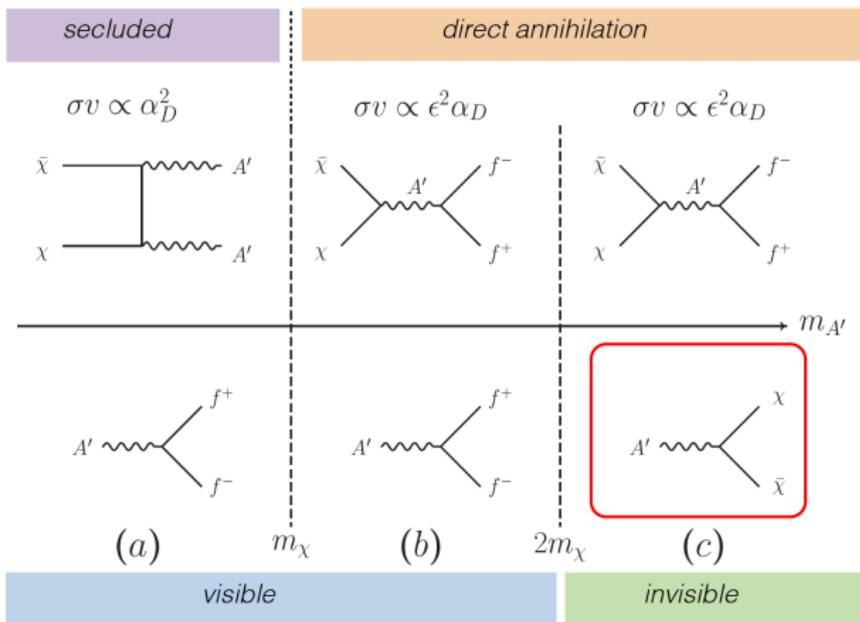
Experimental searches:

- 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**



¹For a comprehensive review: 1707.04591, 2005.01515, 2011.02157

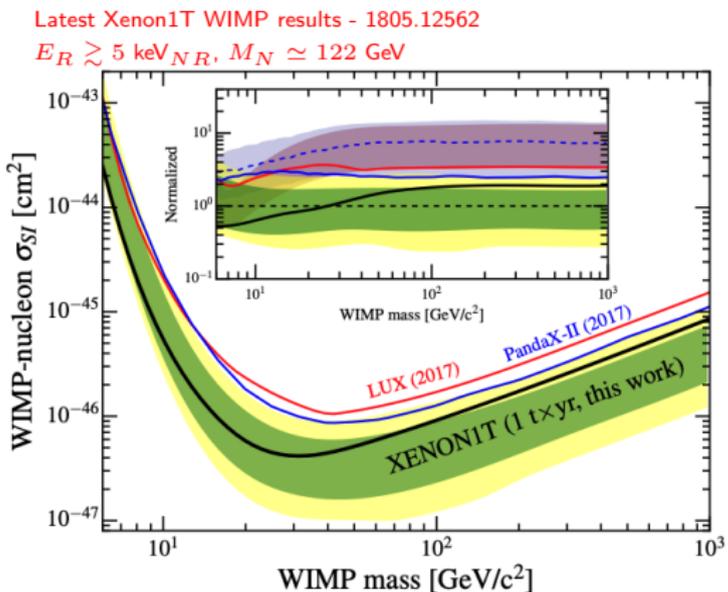
Light dark matter signatures



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

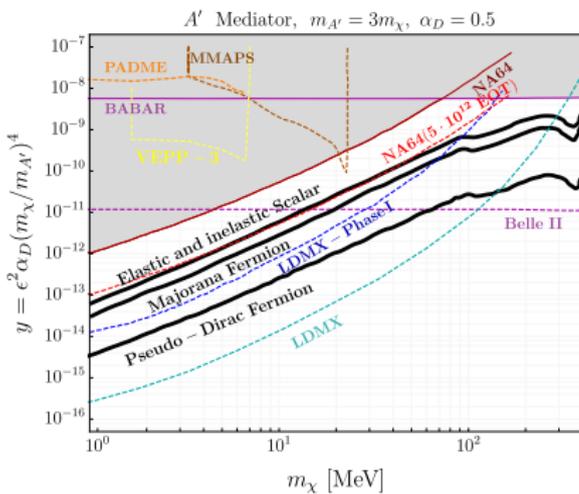
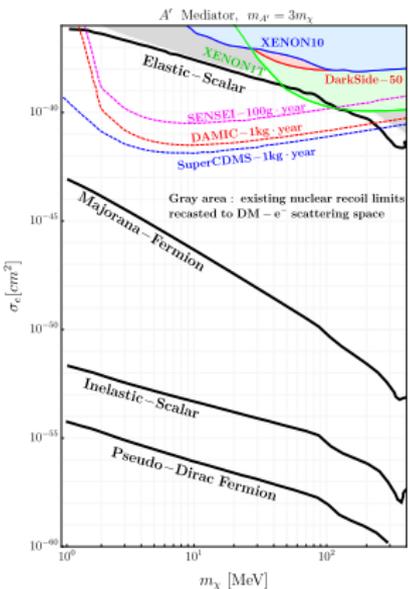
Light dark matter searches at the intensity frontier

- 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



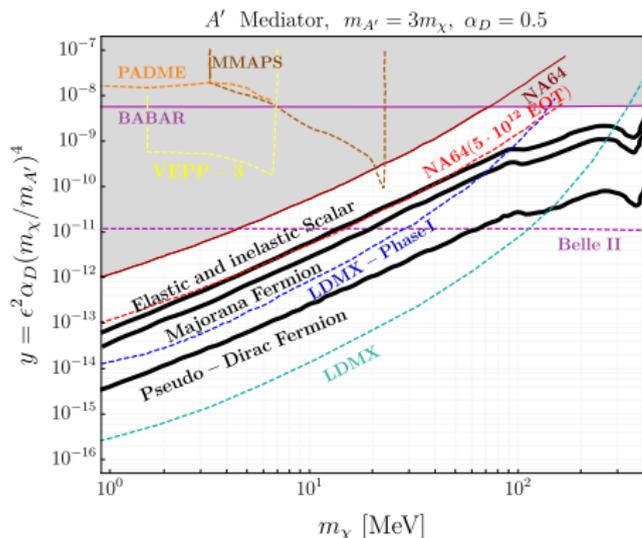
Light dark matter searches at the intensity frontier

- 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



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

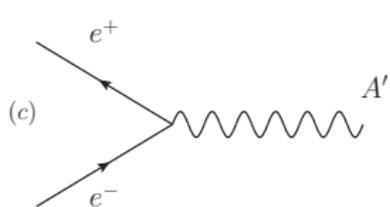
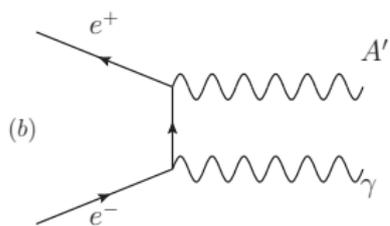
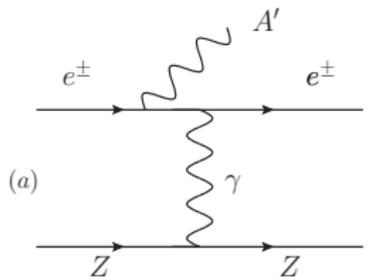


LDM at accelerators

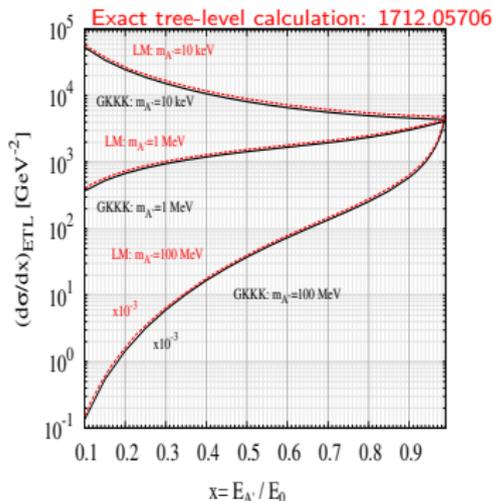
Accelerator-based experiments at the *intensity* frontier are uniquely suited to explore the light dark matter hypothesis

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 $A' \rightarrow \chi\bar{\chi}$
- Scales as $Z^2 \alpha_{EM}^3$
- Forward-boosted, high-energy A' emission

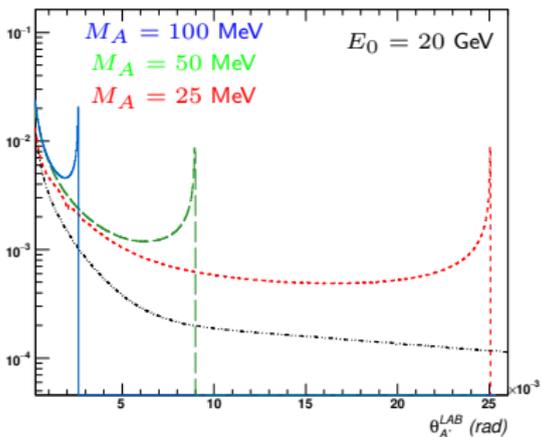
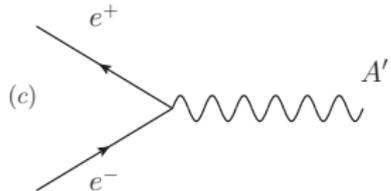
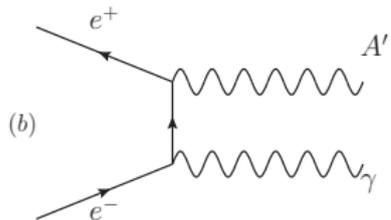
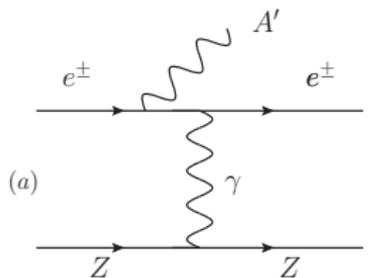


LDM production mechanisms with lepton beams

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

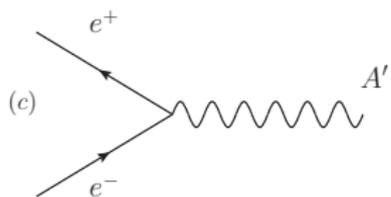
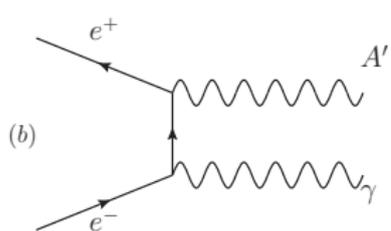
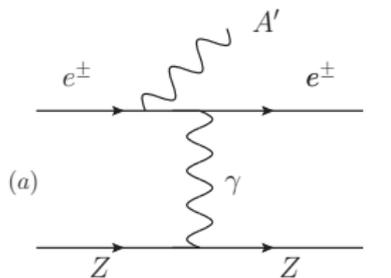
b) Non-resonant e^+e^- annihilation

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



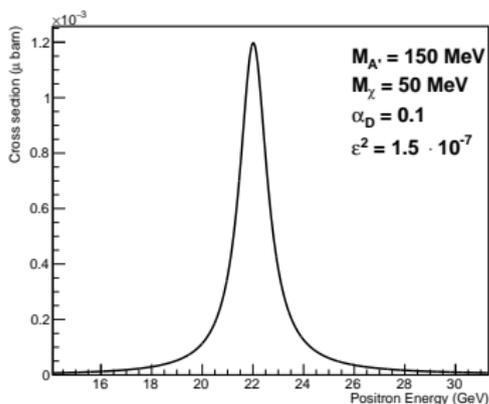
LDM production mechanisms with lepton beams

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



c) Resonant e^+e^- annihilation

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



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

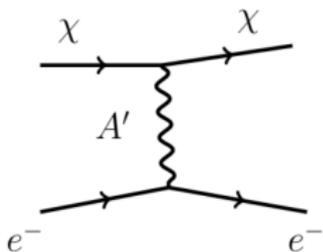
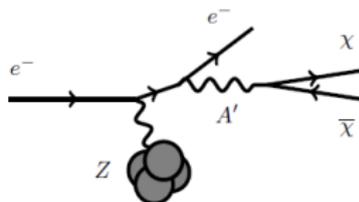
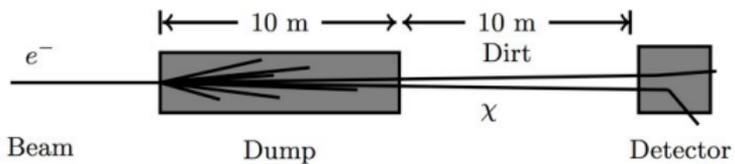
Beam dump experiments: LDM direct detection in a e^- beam, fixed-target setup²

 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 through A' exchange, recoil releasing visible energy
- Different signals depending on the interaction (most promising channel: $\chi - e^-$ elastic scattering)

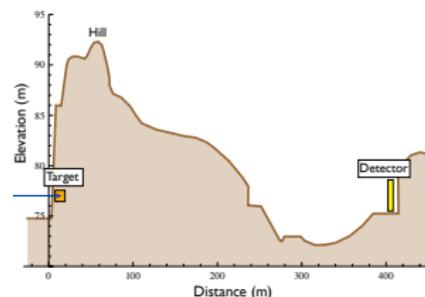


²For a comprehensive introduction: E. Izaguirre *et al*, Phys. Rev. D 88, 114015

E137 at SLAC

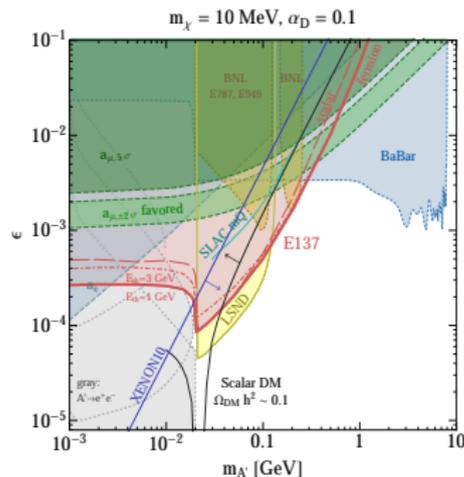
ALPs search experiment, results re-interpreted as LDM search.

- **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:

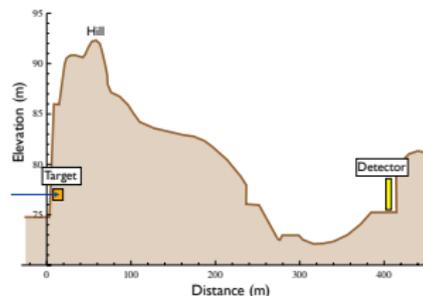
- First analysis focused on A' -strahlung production mechanism (Phys. Rev. Lett. 113, 171802 (2014))
- New analysis focused on secondary positrons: new resonant production mechanism $e^+e^- \rightarrow \chi\bar{\chi}$ (Phys. Rev. Lett. 121, 041802 (2018))



E137 at SLAC

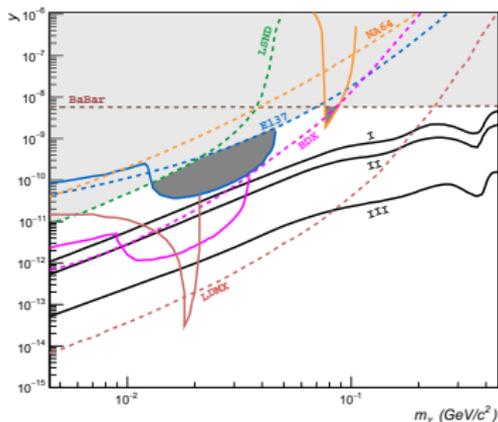
ALPs search experiment, results re-interpreted as LDM search.

- **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 $e^+e^- \rightarrow \chi\bar{\chi}$ (Phys. Rev. Lett. 121, 041802 (2018))



BDX: Beam Dump eXperiment

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

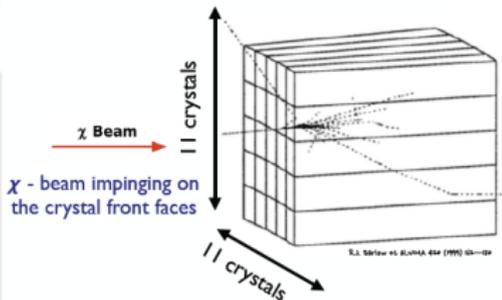
Experimental setup

- Detector installed $O(20\text{ m})$ 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 ($\simeq 10\text{ m}$ 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

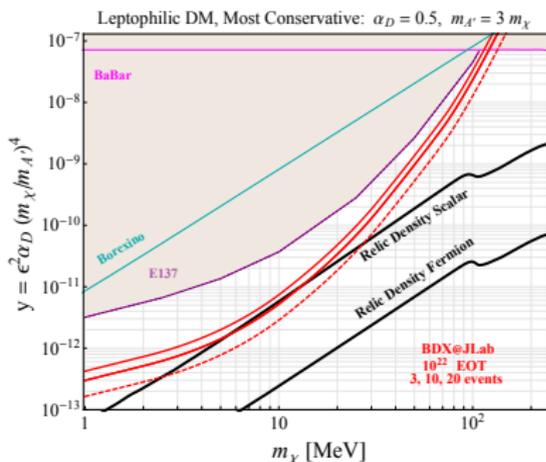
Total active volume: $\simeq 0.5\text{ m}^3$



BDX: reach and status

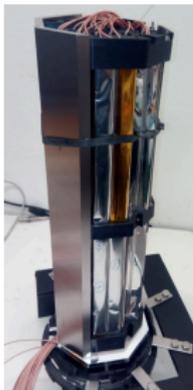
BDX reach:

- With $O(10^{22})$ EOT, BDX can explore a 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

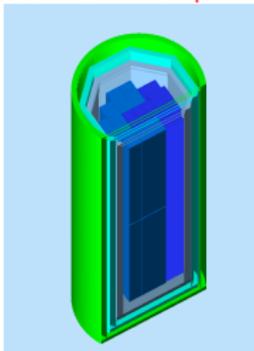


Experiment status:

- 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



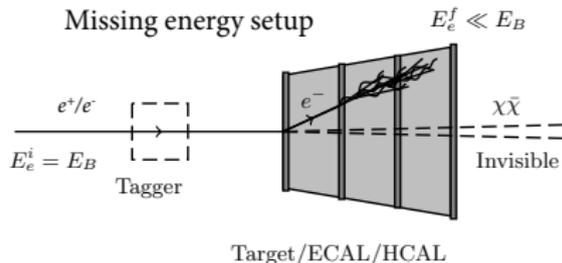
Fixed *active* thick-target LDM searches: missing energy experiments

Beam-dump experiments pay a penalty $N_S \propto \epsilon^4$ in the event yield:
production \times detection

New approach: missing energy measurement - the *active thick target* is the detector, $N_S \propto \epsilon^2$

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

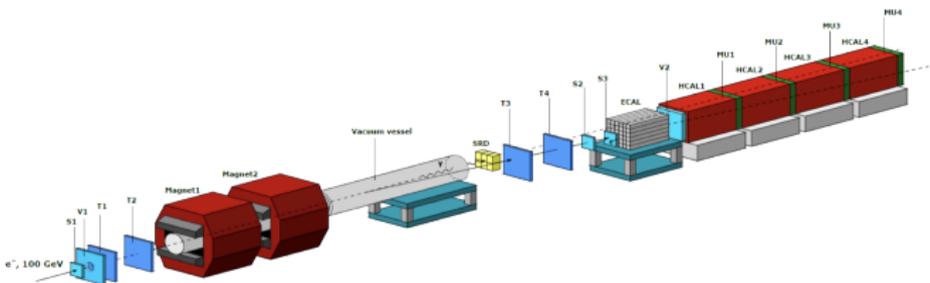
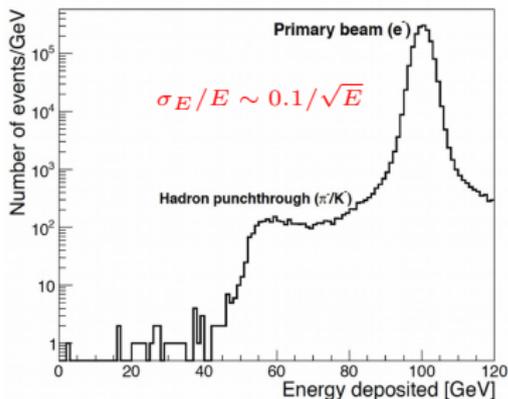


NA64

Missing energy experiment at CERN North Area, 100 GeV e^- beam³

Experiment Setup

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

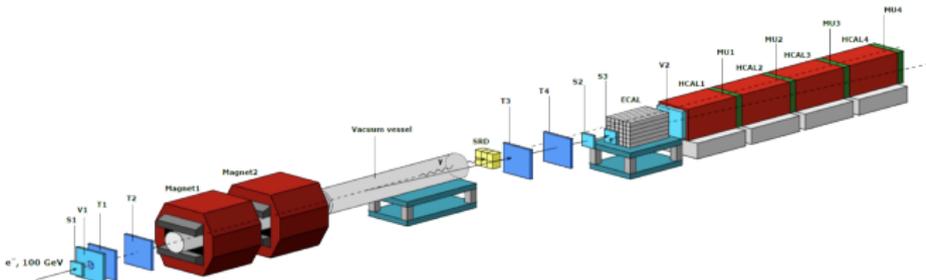
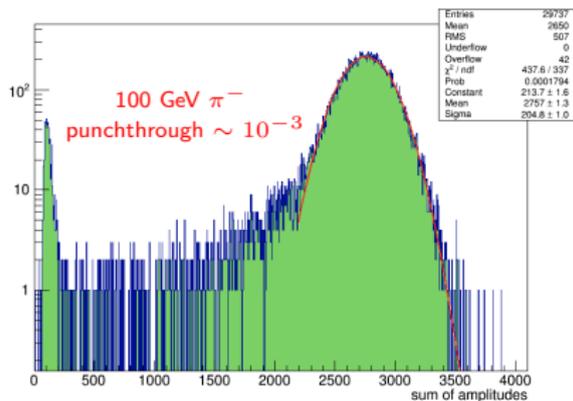
³Phys.Rev.Lett. 123 (2019) 121801

NA64

Missing energy experiment at CERN North Area, 100 GeV e^- beam³

Experiment Setup

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

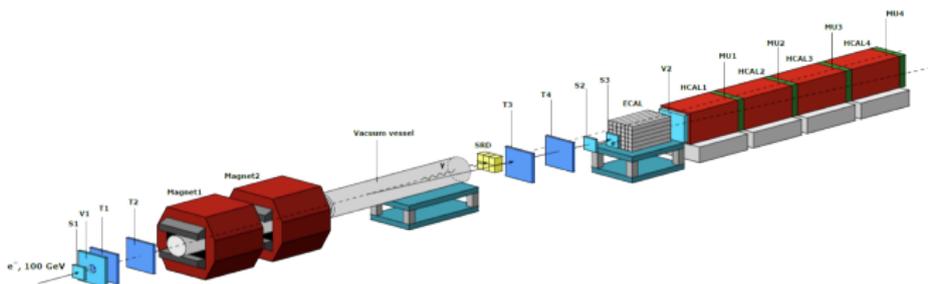
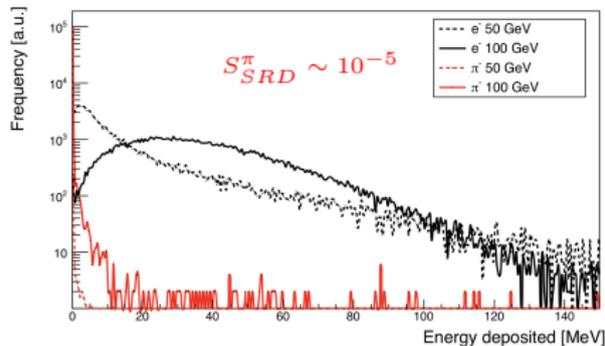
³Phys.Rev.Lett. 123 (2019) 121801

NA64

Missing energy experiment at CERN North Area, 100 GeV e^- beam³

Experiment Setup

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



³Phys.Rev.Lett. 123 (2019) 121801

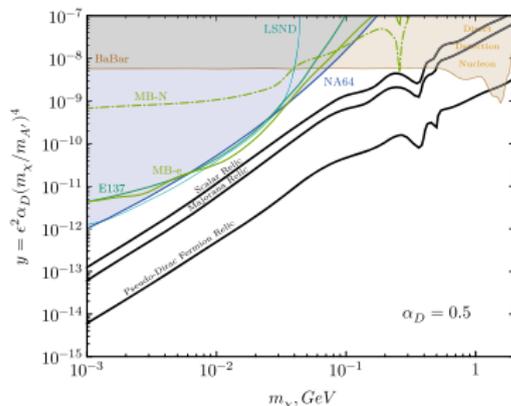
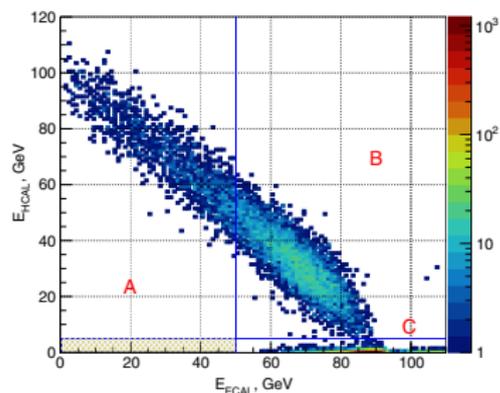
NA64

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 ~ 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
$\mu \rightarrow e\nu\nu$, π , $K \rightarrow e\nu$, 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 **darK** matt**ER**

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

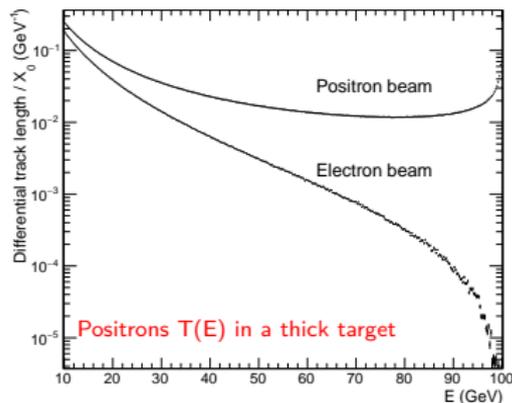
Why positrons?

Signal production reaction: $e^+e^- \rightarrow A' \rightarrow \chi\bar{\chi}$

- Large event yield:

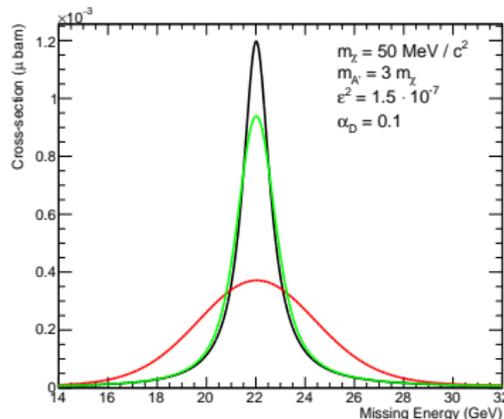
$$N_s^{annihil} \propto Z\alpha_{EM} \text{ vs } N_s^{brem} \propto Z^2\alpha_{EM}^3$$

- 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 accessible with the new methodology



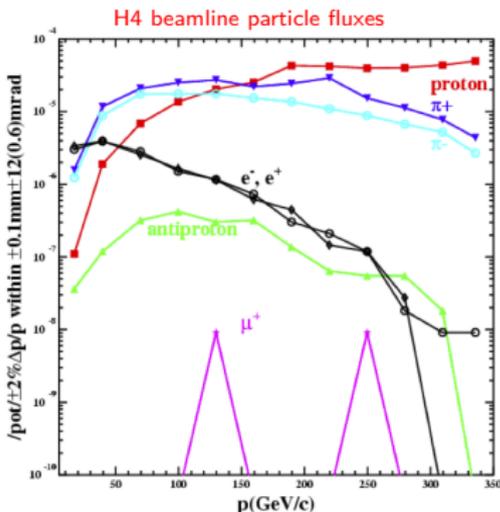
POKER

Key POKER elements

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

POKER strategy:

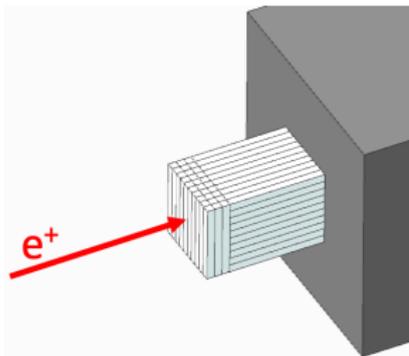
- **Beam:** exploit the H4 beamline at CERN and the NA64 beam tagging and diagnostic devices
 - H4 beam: 100 GeV e^+ with $1e^+/\mu s, \approx 10^{10} e^+$ ot/day
- **Veto:** re-use the existing NA64 hadronic calorimeter
- **Active target:** design and construct an optimized, high-resolution EM calorimeter



POKER active target

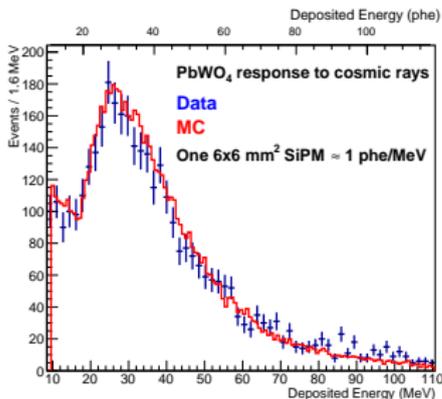
Preliminary design: $35X_0$ PbWO₄ calorimeter with SiPM readout

- 10x10 matrix of 20x20x250 mm³ crystals
+ 3 layers in front
 - Absorb high-energy γ produced by Bremsstrahlung in first few X_0 at level $10^{-13}/e^+$ or t
 - Avoid transverse energy leakage
- Required $\sigma_E/E \sim 2\%/\sqrt{E}$
 - $LY \sim 2.5 \text{ phe/MeV}$
 - Use four 6x6 mm² 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
- $\phi_n \leq 10^4 \text{ n}_{eq} \text{ cm}^{-2}\text{s}^{-1}$: no effects expected



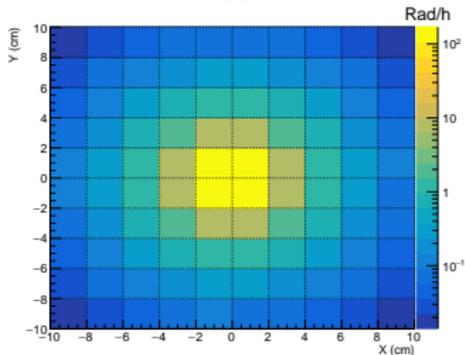
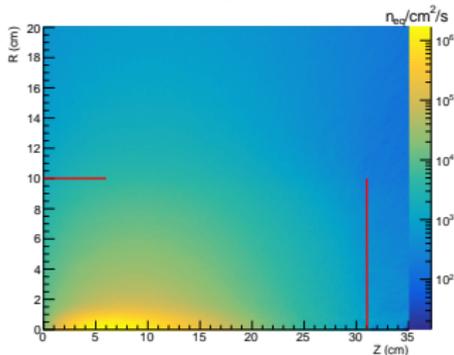
POKER active target

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

- 10×10 matrix of $20 \times 20 \times 250$ mm³ crystals
+ 3 layers in front
 - Absorb high-energy γ produced by Bremsstrahlung in first few X_0 at level $10^{-13}/e^+$ ot
 - Avoid transverse energy leakage
- Required $\sigma_E/E \sim 2\%/\sqrt{E}$
 - $LY \sim 2.5$ phe/MeV
 - Use four 6×6 mm² SiPMs, $25 \mu\text{m}$ 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⁻²s⁻¹: no effects expected

Radiation dose from 100 GeV e^+ at 1 MHzNeutrons flux from 100 GeV e^+ at 1 MHz

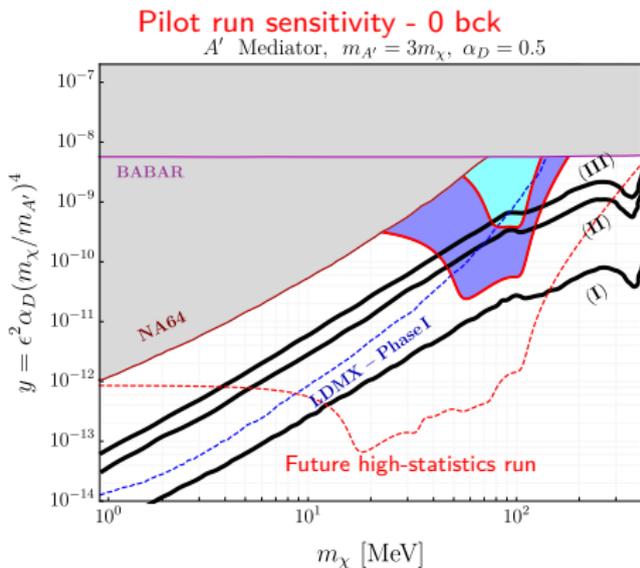
POKER sensitivity to LDM

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



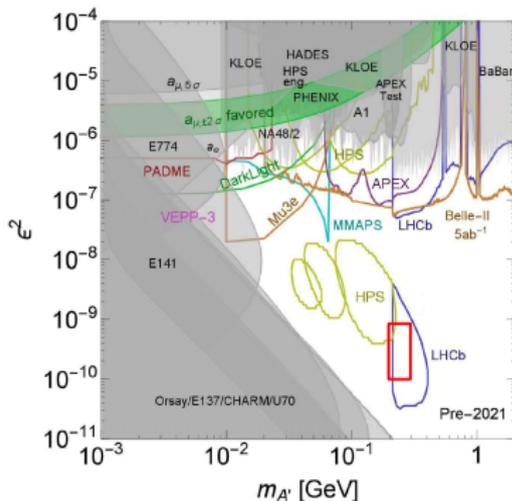
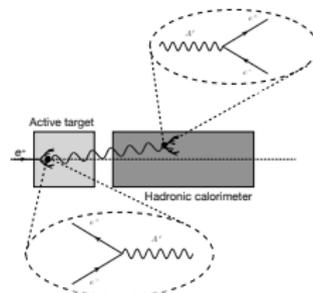
POKER sensitivity to LDM

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



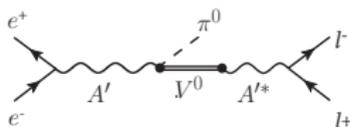
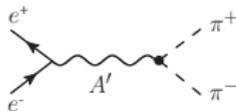
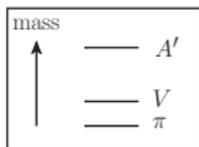
POKER sensitivity to LDM

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

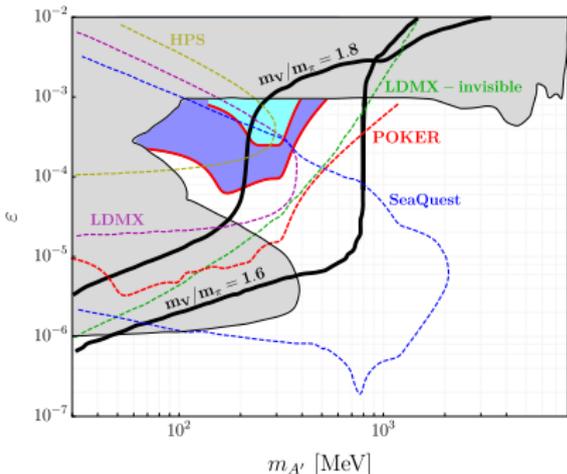
- **Baseline scenario:** $5 \cdot 10^{10}$ e^+ ot, 50 GeV missing energy threshold
- **Aggressive scenario:** $3 \cdot 10^{11}$ e^+ ot, 25 GeV missing energy threshold
- **Future experimental program with multiple 10^{13} e^+ ot runs at different energies**

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

- Visible-decaying A'
- Strongly Interacting Massive Particles



A' Mediator, $m_{A'} = 3m_\pi$



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				■	■

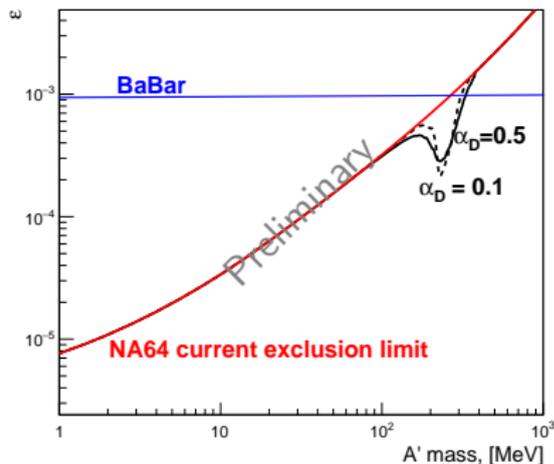
- Pilot run measurement expected in 2024, matched to LHC injectors schedule

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.



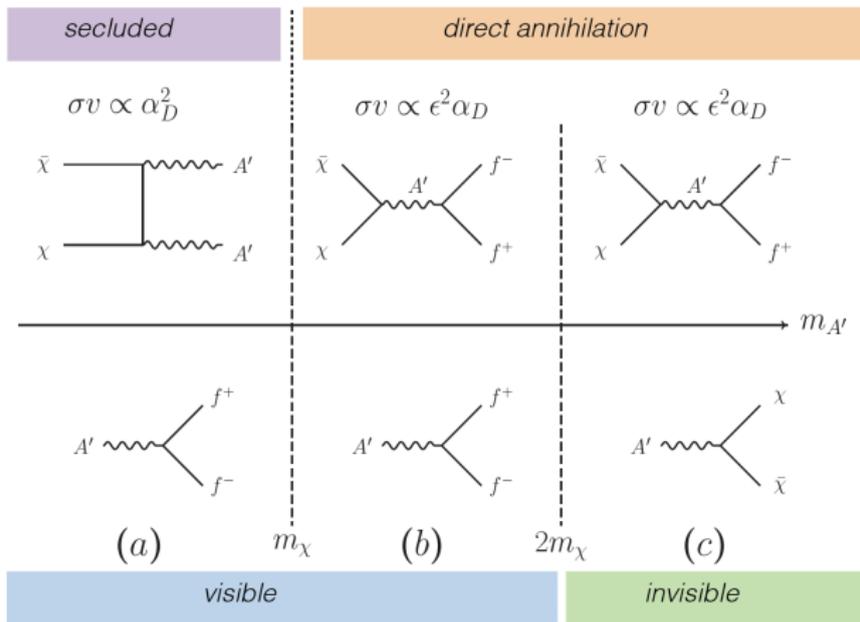
Conclusions

- 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 **darK** 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!!!

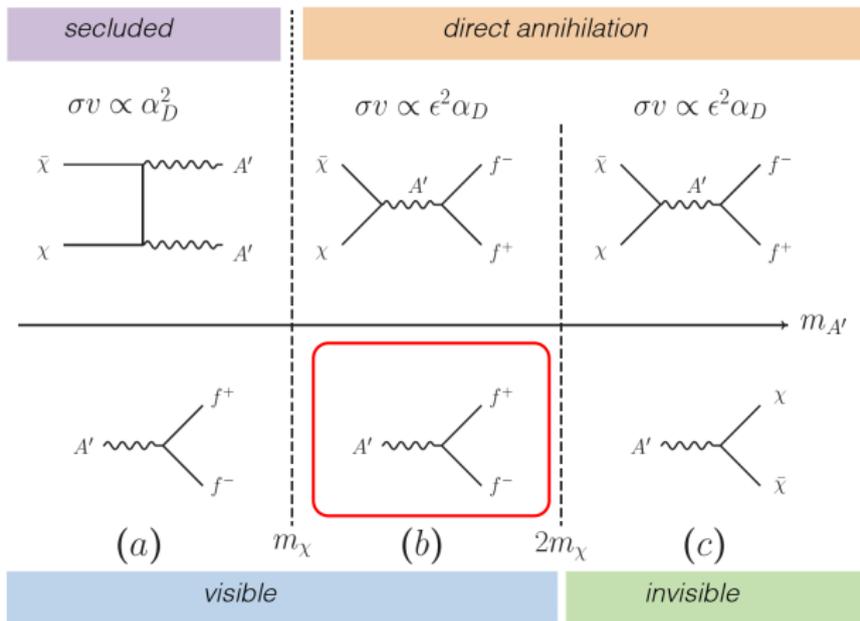
Backup slides

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

Light dark matter signatures

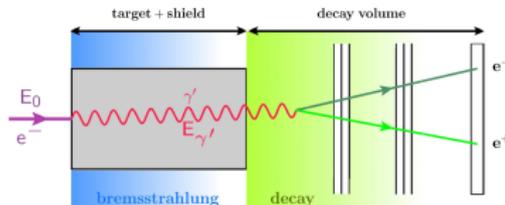


- (a) $m_{A'} < m_\chi$: **secluded** scenario. Provides no thermal target for accelerator-based experiments: **any** ϵ value is allowed.
- (b) $m_\chi < m_{A'} < 2m_\chi$: **visible decay** scenario (although off-shell $\chi - \bar{\chi}$ production is allowed!)
- (c) $m_{A'} > 2m_\chi$: **invisible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

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

Reaction topology:

- A' production: radiative A' emission
 $e^- N \rightarrow e^- N A'$
- 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.

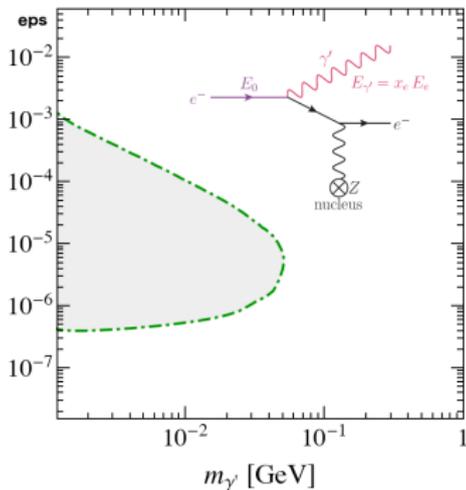


Number of events:

Dependence on main parameters⁴:

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

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



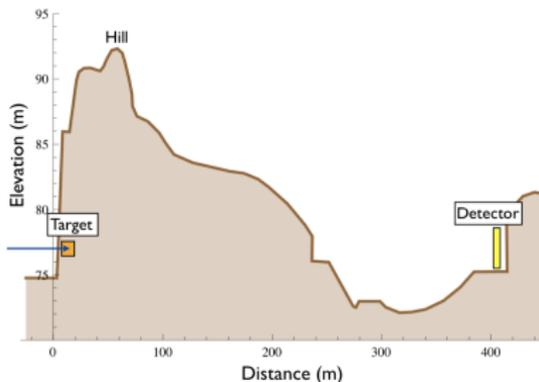
⁴For a review: S. Andreas, Phys.Rev. D86 (2012) 095019

E137 at SLAC

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

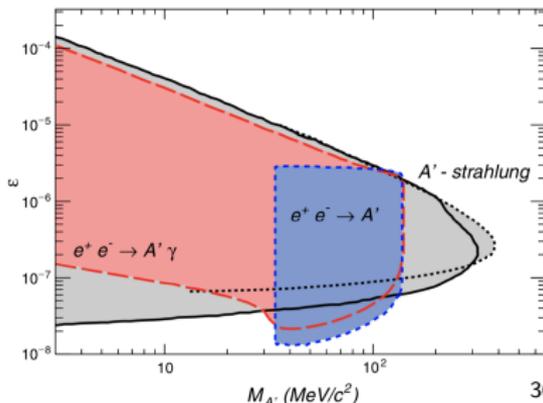
Experiment Parameters:

- **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^-

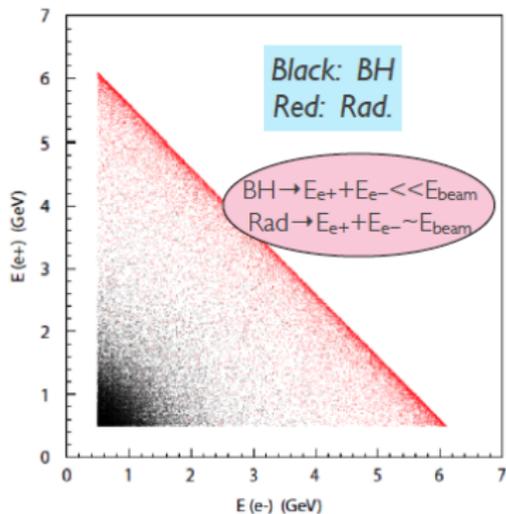
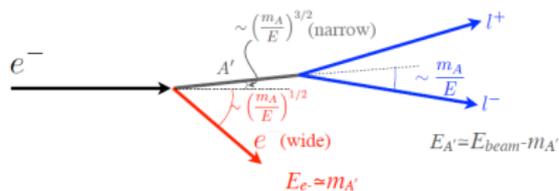


A' production and visible decay detection in a fixed thin-target setup

Radiative production mechanism:
 $e^- N \rightarrow e^- N A' \rightarrow e^- N e^+ e^-$, $e^+ e^-$
 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 continuous QED background
- Low ε : **detached-vertex search**

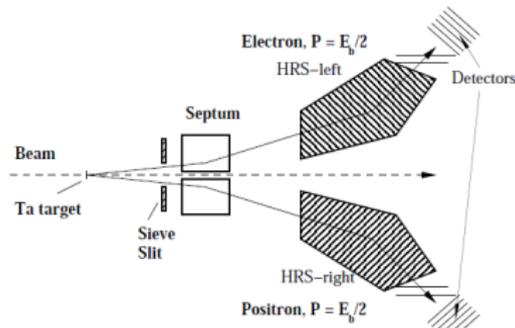


APEX: setup

JLab Hall-A experiment⁵: two-arms spectrometers resonance search (“bump-hunting”) for 50 – 500 MeV A' decaying promptly to e^+e^- .

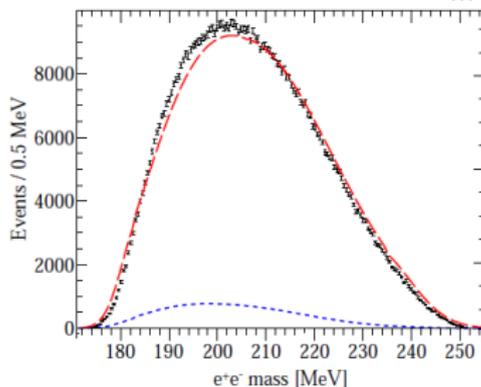
Setup:

- 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: $0.85 \div 1.11$ MeV



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

APEX: results and status

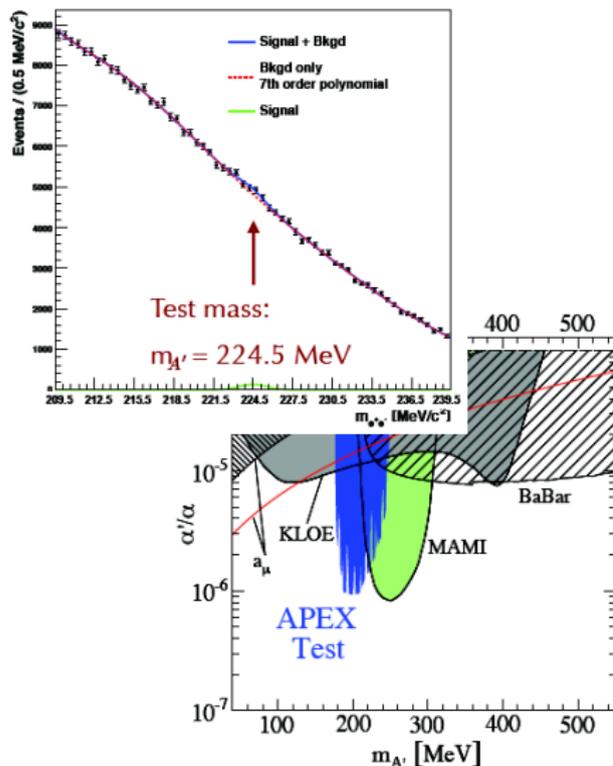
APEX 2010 test run: no signals were observed. Exclusion limits were set for $m'_A = 178 \dots 250$ MeV, $\varepsilon^2 > 10^{-6}$.

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 (7th 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

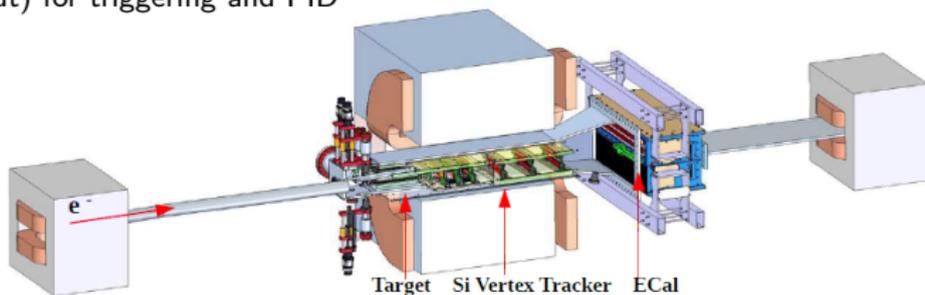
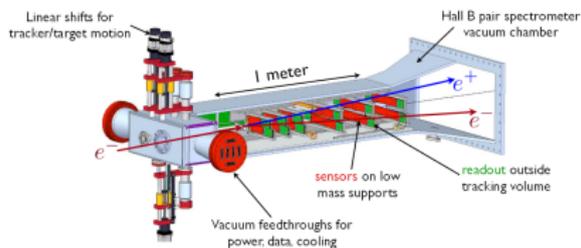


HPS: setup

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



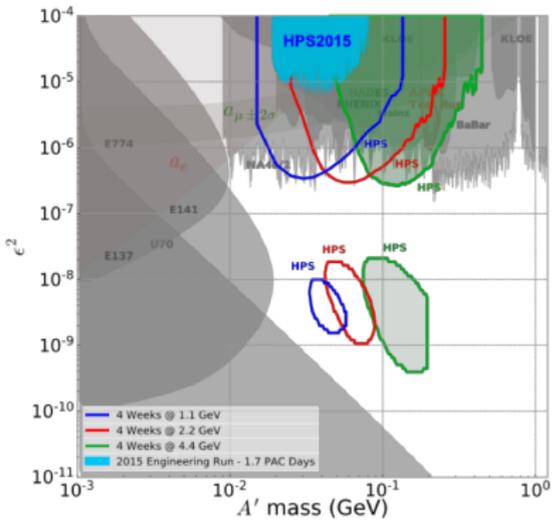
HPS: results and status

- July 2012: HPS demonstrated the feasibility of the measurement and the operation of the detector in a test run³
- Spring 2015: 1.7 PAC days @ 1.06 GeV. Results published in PRD rapid communications⁴
- 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.

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. Bondi,⁴ S. Boyarinov,² S. Bueltmann,⁵ V. D. Burkert,² D. Calvo,⁶ M. Carpinelli,⁷ A. Celentano,⁸ G. Charles,⁹ L. Colameri,^{10,11} W. Cooper,¹² C. Cuevas,¹³ A. D'Angelo,^{10,11} N. Dashyan,¹⁴ M. De Napoli,¹⁵ R. De Vita,¹⁶ A. Durr,¹⁷ R. Dupre,¹⁸ H. Egiyan,² L. Elougaheiri,² R. Essig,¹⁹ V. Falyshev,²⁰ C. Field,¹⁷ A. Filippi,²¹ A. Freyberger,²² M. Garçon,²³ N. Gevorgyan,²⁴ F. X. Girod,²⁵ N. Graf,²⁶ M. Graham,²⁷ K. A. Griffioen,²⁸ A. Grillo,²⁹ M. Guidal,³⁰ R. Herbst,³¹ M. Holtrop,³² J. Jaros,³³ G. Kalicy,³⁴ M. Khandaker,³⁵ V. Kubarovsky,³⁶ E. Lescnora,³⁷ K. Livingston,³⁸ T. Maruyama,³⁹ K. McCarthy,⁴⁰ J. McCormick,⁴¹ B. McKinnon,⁴² K. Moffeit,⁴³ D. Moreno,⁴⁴ C. Muñoz Camacho,⁴⁵ T. Nelson,⁴⁶ S. Niccolai,⁴⁷ A. Odian,⁴⁸ M. Ottunio,⁴⁹ M. Osipenko,⁵⁰ R. Patermarzian,⁵¹ S. Paul,⁵² N. Randazzo,⁵³ B. Raydo,⁵⁴ B. Reese,⁵⁵ A. Rizzo,^{56,57} P. Schuster,^{58,59} Y. G. Sharabian,⁶⁰ G. Simi,^{61,62} A. Simonyan,⁶³ V. Sipala,⁶⁴ D. Sokhan,⁶⁵ M. Solt,⁶⁶ S. Stepanyan,⁶⁷ H. Szumila-Vance,⁶⁸ N. Toro,⁶⁹ S. Uemura,⁷⁰ M. Ungaro,⁷¹ H. Voskanyan,⁷² L. B. Weinstein,⁷³ B. Wojtsekhowski,⁷⁴ and B. Yake⁷⁵

(Heavy Photon Search Collaboration)



³ Nucl. Instrum. Meth. A **777** (2015) 91
⁴ Phys. Rev. D **98**, 091101 (2018)

Missing *momentum* experiment with multi-GeV electron beam⁶

Goal: 10^{16} EOT in few years $\sim 1e^{-}/10$ ns!

Very challenging detector design

- **Fast Si tracker**

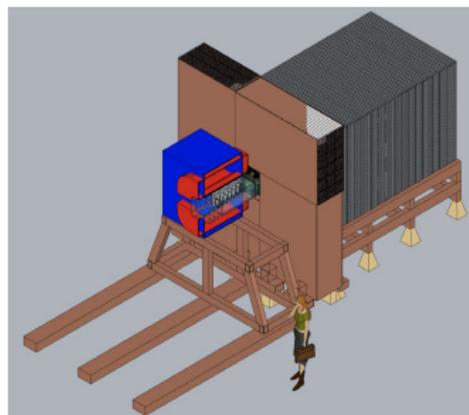
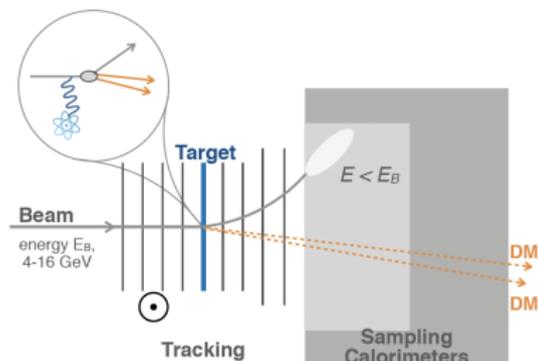
- Tagging tracker in 1.5 T field
- Recoil tracker in fringe field
- W (0.1-0.3 X_0) target in between

- **EM Calorimeter**

- Design based on ongoing CMS forward Si/W calorimeter upgrade

- **Hadron Calorimeter**

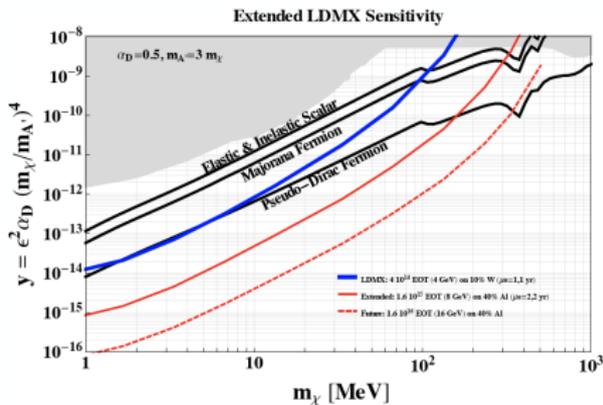
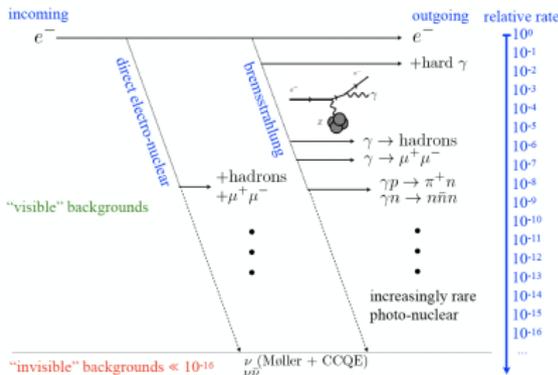
- Veto for penetrating hadrons (most critical: neutrons)
- Sci/steel sampling design
- Hermetic: surrounds ECAL on back and on sides



⁶ Baseline design paper: arXiv:1808.05219

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

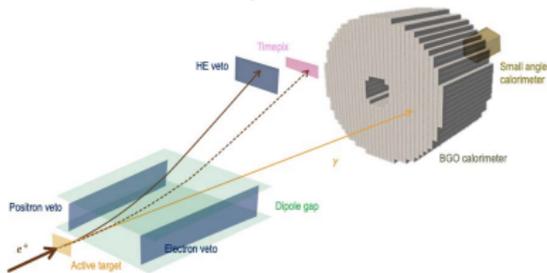


Missing mass searches

Positron beam impinging on a **thin target**: mono-photon missing mass resonance search in the reaction $e^+e^- \rightarrow A'\gamma$. 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

