SOCIETÀ ITALIANA DI FISICA
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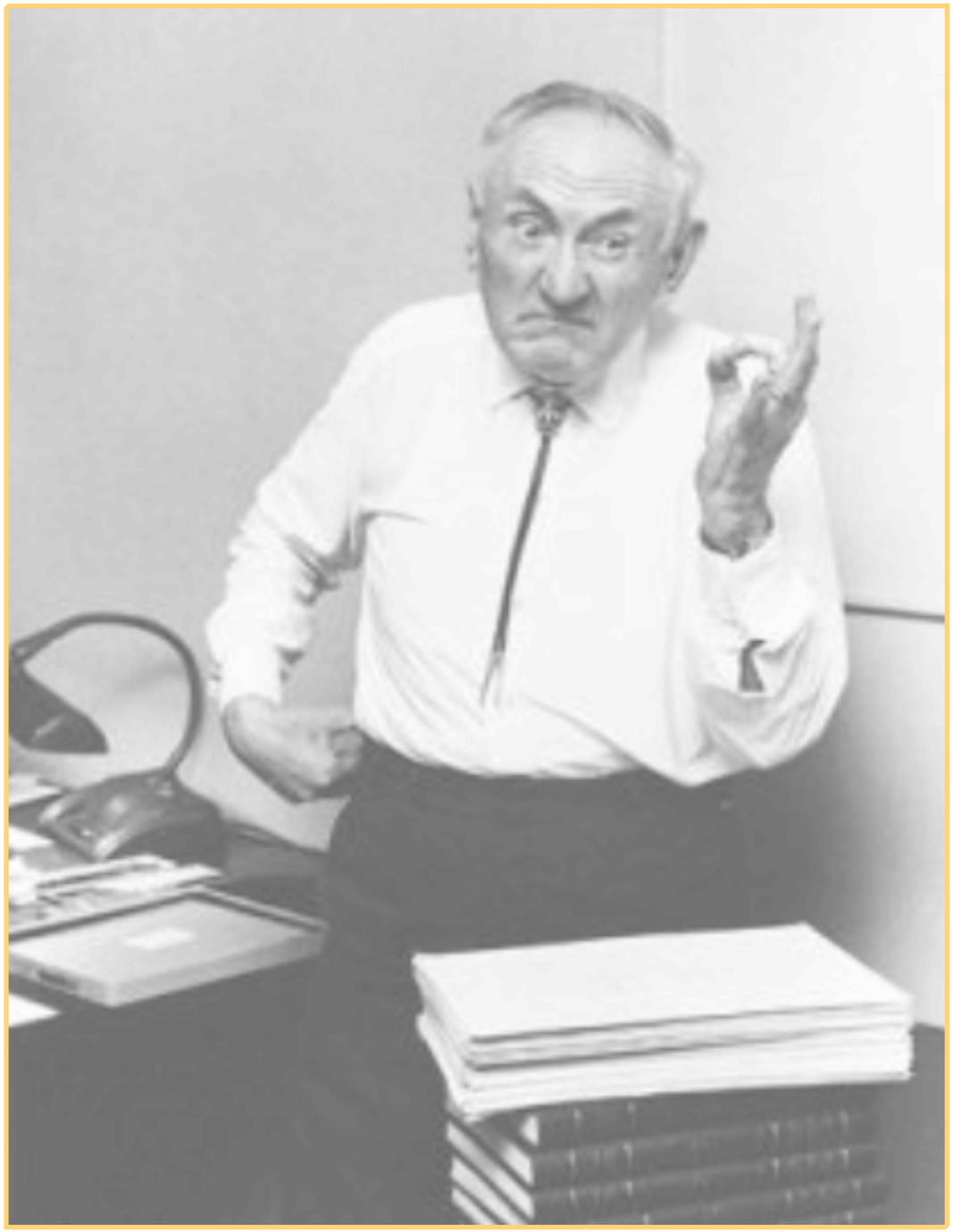
BRINGING THE DARK SECTOR INTO THE LIGHT

M.Bondì[1], **I.Oceano**[2,3]

[1]INFN - Sezione di Genova (mariangela.bondi@ge.infn.it)

[2]INFN - Sezione di Lecce (isabella.oceano@le.infn.it)

[3]Università del Salento



DARK PHOTON

NEUTRAL DOORS -*PORTALS*- TO INCLUDE DM IN THE SM

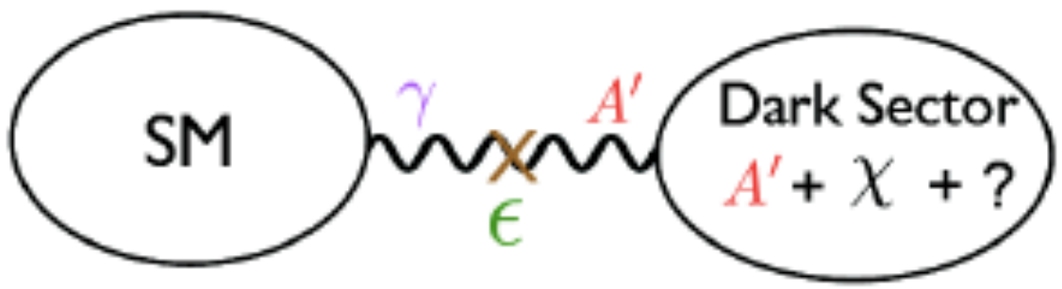
- There are many possibly ways to introduce the Dark Matter into the Standard Model
- A simple way to go beyond the SM
  - $SU(3) \times SU(2) \times U(1)_Y \times U(1)_D$

💡 Introduction of a new Gauge symmetry $U(1)_D$

  - $L \sim g' q_f \bar{\psi}_f \gamma^\mu \psi_f A'_\mu$
  - New massive Gauge Boson A' : dark photon
    - U(1) breaking mechanism
      - Higgs like mass for A' → dark Higgs existence needed
      - Stuckelberg mechanism → The only new light state remains A'

👍 Weak interaction with SM through ϵ

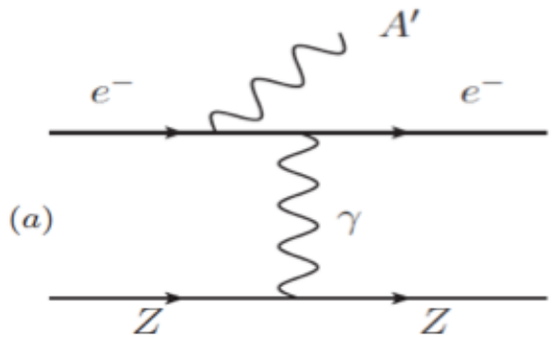
  - $L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$

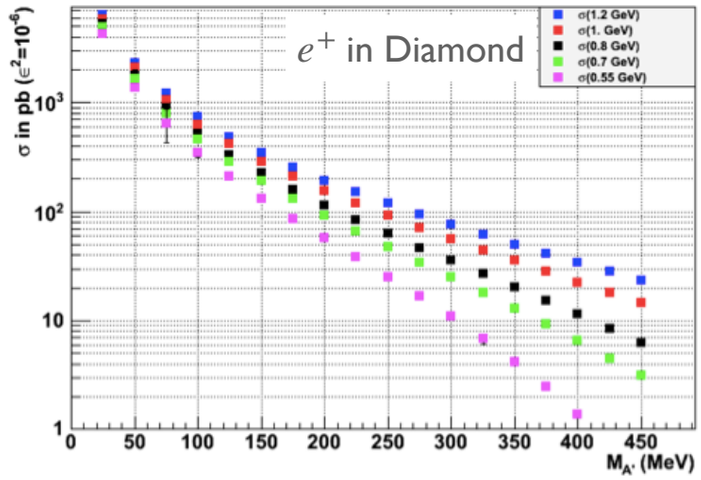


Kinetic mixing coefficient

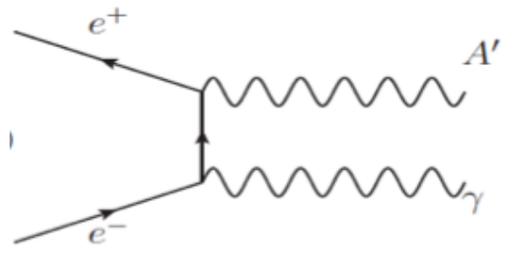
A’ PRODUCTION

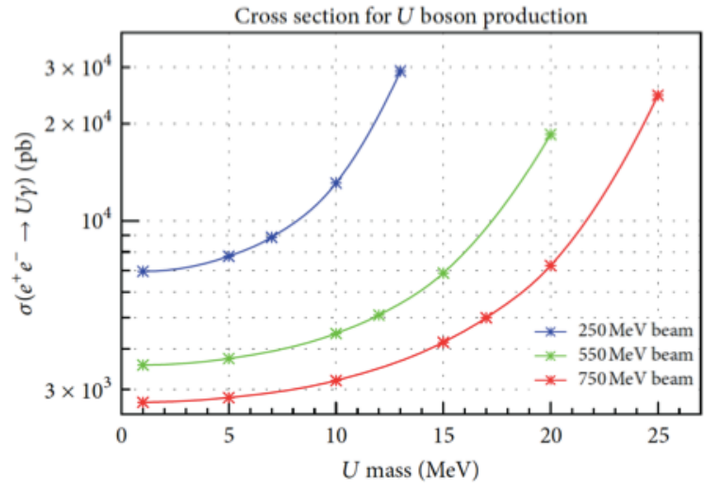
- Production mechanism allowed
  - A-strahlung
    - $\sigma \propto \frac{\alpha^3 \epsilon^2}{m_{A'}^2}$



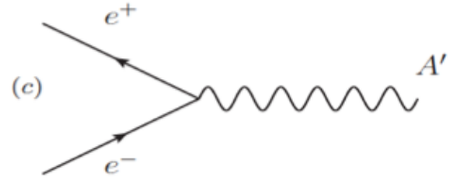


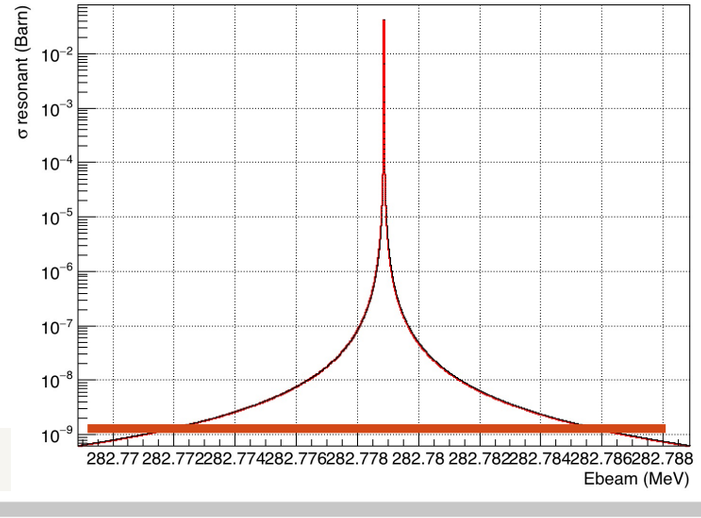
  - Associated production
    - If $m_{A'} << s$ $\quad \sigma \propto 2\epsilon^2 \sigma(e^+e^- \to \gamma\gamma)$
    - Limited range in mass $m_{A'} \leq \sqrt{2 m_e E_{beam}}$





  - Resonant annihilation



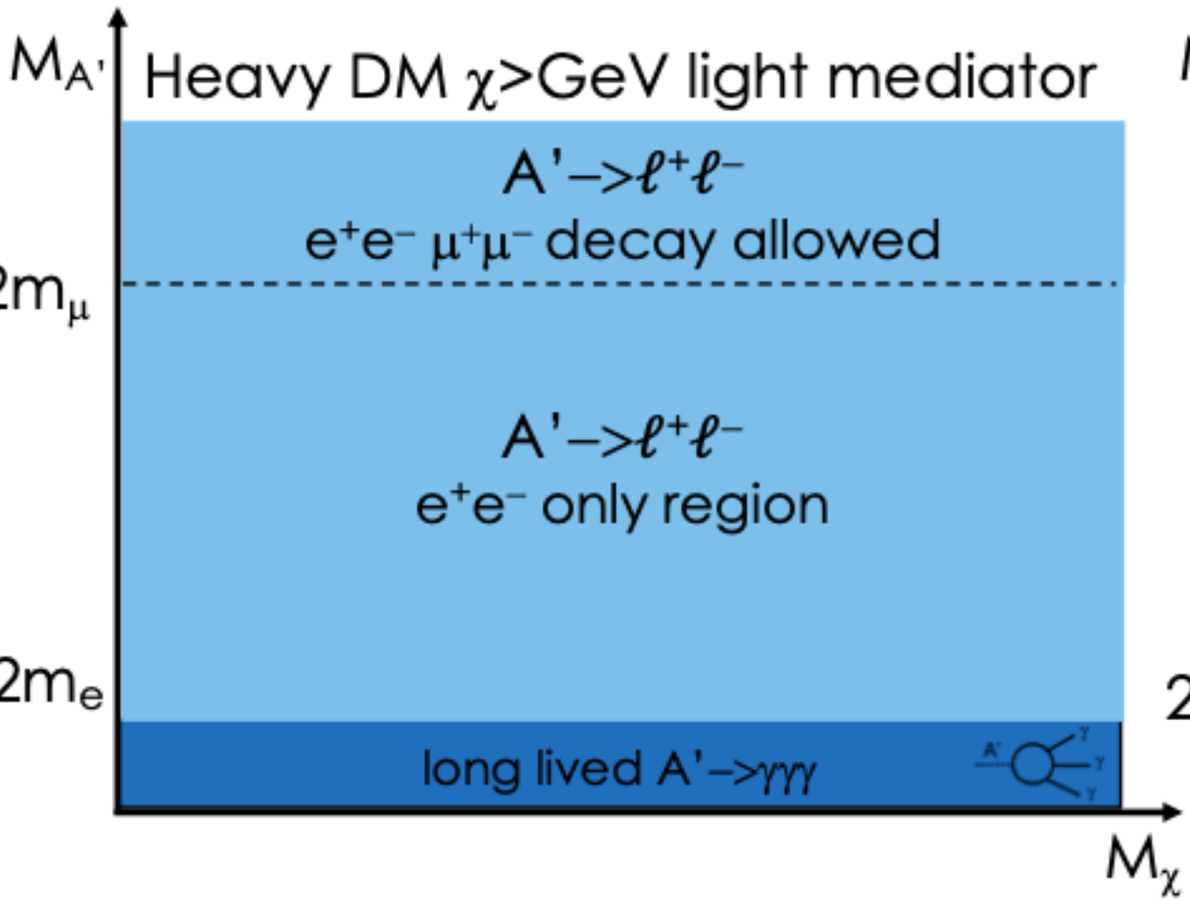


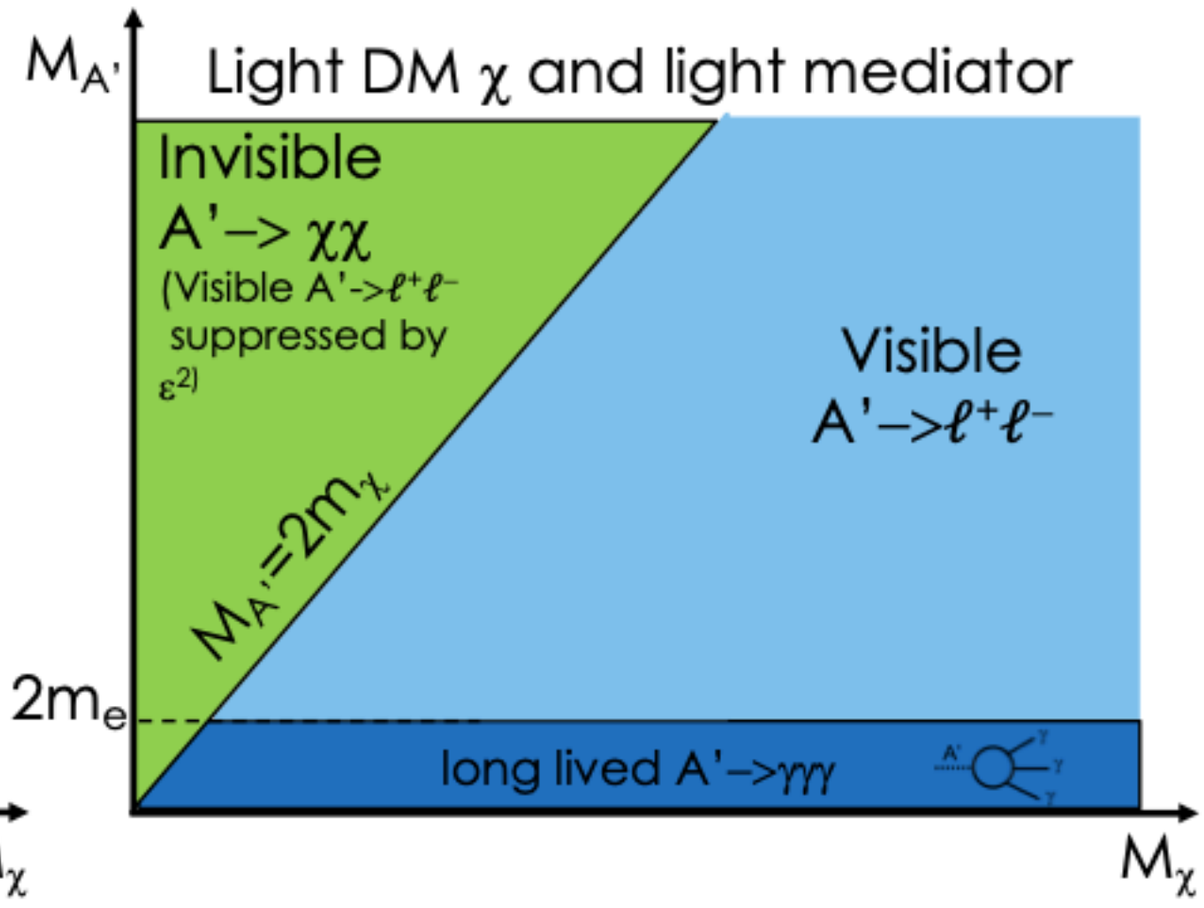
A’ DECAY MODES MEV-GEV SCALE

Decays
– To SM model particles if $2M_{DM} > M_{A'} > 2m_e$
– To DM (invisible) particles if $2M_{DM} < M_{A'}$

A’ search

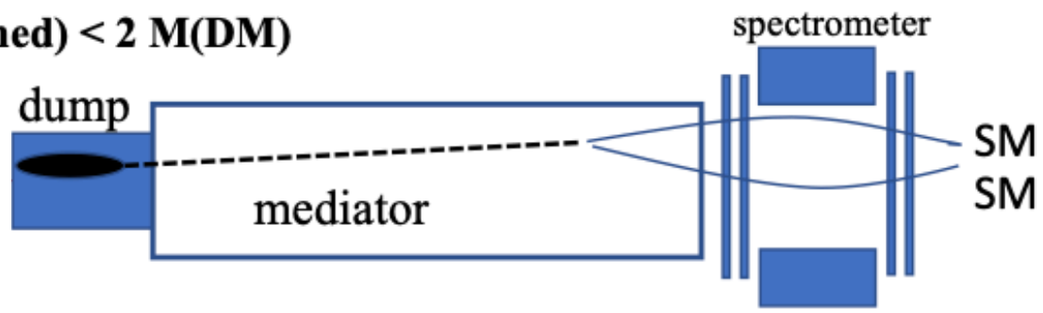
-visible decay
-invisible decay



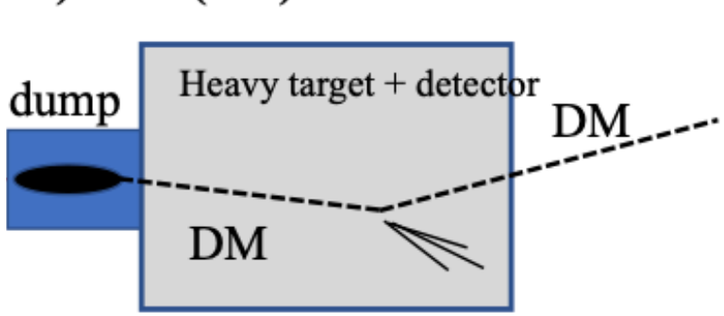


EXPERIMENTAL TECHNIQUES

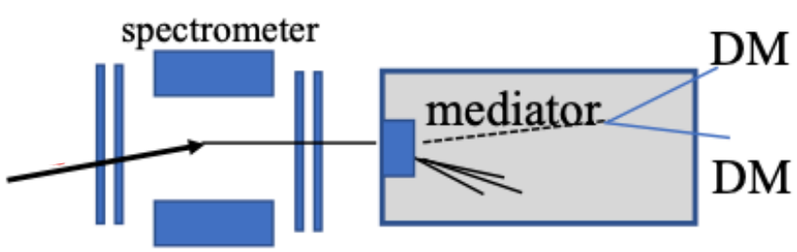
M(med) < 2 M(DM)



M(med) > 2 M(DM)



M(med) > 2 M(DM)



Visible final state:

Bump searches:

- NA62@CERN, p@400 GeV, $N_{pot} = 10^{18} - \sim 10^{19}$
- SHADOWS (proposal), p@400 GeV, $N_{pot} = \sim 10^{19}$
- NA64@CERN, e@100 GeV, N_{pot}: $10^{12} - 10^{13}$
- SHiP@CERN (proposal), p@400 GeV, $N_{pot} = 2 \times 10^{20}$
- **HPS**, APEX, DarkLight @ JLAB e@1-10 GeV
- Sea(Dark)QUEST @ FNAL, p@120 GeV, $N_{pot} = 10^{18} - 10^{20}$
- …

Invisible final state:

DM scattering with DM medium:

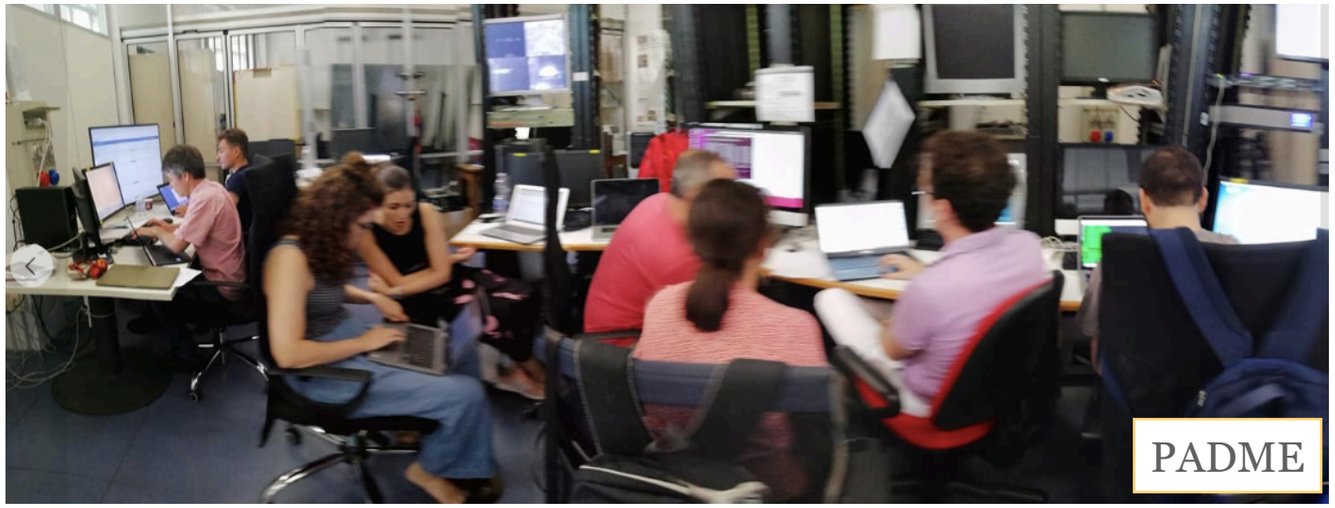
- **BDX** @ JLAB, e @ 11 GeV, $N_{pot} = 10^{22}$
- MiniBooNE@FNAL, p@8 GeV, $N_{pot} = 10^{20}$
- SHiP@CERN (proposal), p@400 GeV, $N_{pot} = 2 \times 10^{20}$
- …

Invisible final state:

Missing mass/energy/momentum:

- NA64(e)@CERN, e@100 GeV, $N_{pot} = 10^{12} - 10^{13}$
- NA62@CERN, 10^{13} K decays
- LDMX @ SLAC (proposal), e@4-8 GeV
- **PADME** @ LNF, p@ 500 MeV , $N_{pot} = 4 \times 10^{13}$
- **POKER** @CERN, p@100GeV, $N_{pot} = 5 \times 10^{10}$
- …

PADME


PADME


BDX/HPS/POKER

EXPERIMENTS LOOKING FOR DARK SECTOR


BDX/HPS/POKER


BDX/HPS/POKER


PADME

Dark sector search

- PADME
- HPS
- BDX
- POKER
- JPOS

POSITRON ANNIHILATION INTO DARK MEDIATOR EXPERIMENT- PADME @ LNF

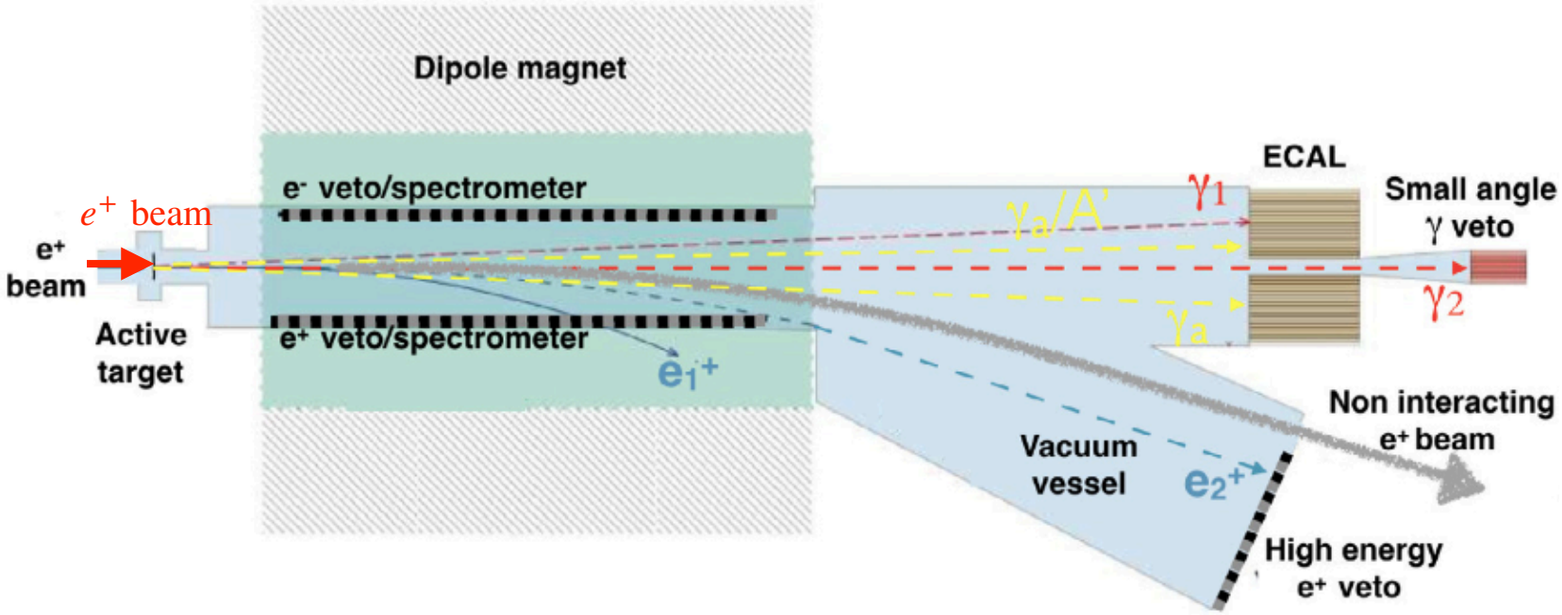
- e^+ fixed target experiment searching for dark photons with $M_{A'} \leq 23.7$ MeV

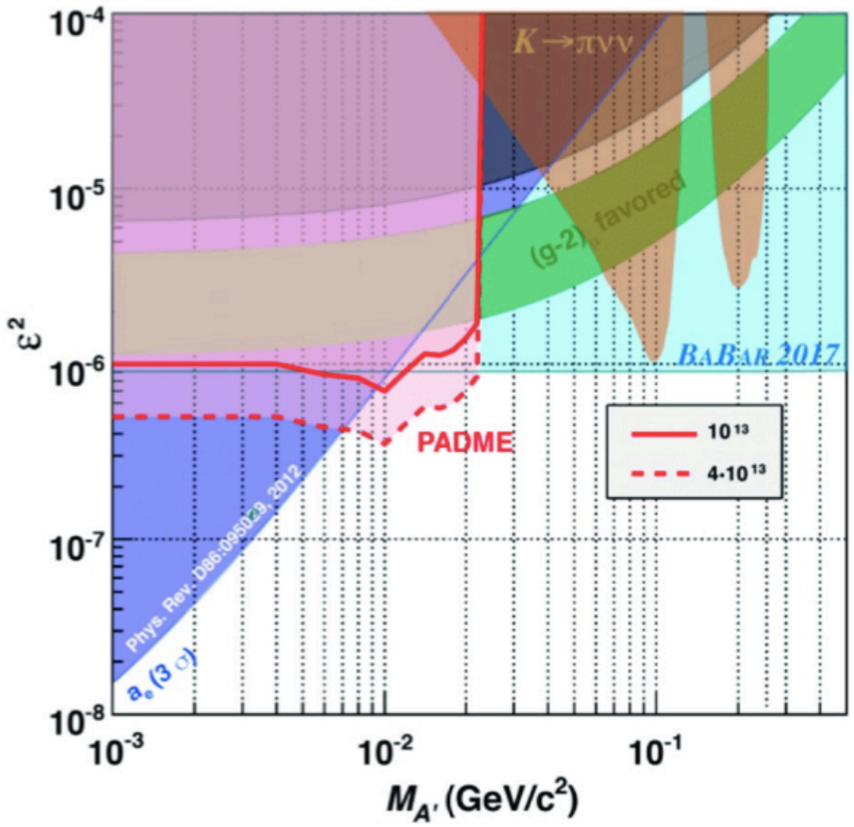
LDM production

- $e^+e^- \rightarrow \gamma A'$
- A' invisible decay

LDM detection

- Missing mass technique used
  Goal: 4×10^{13} POT (Positrons On Target)

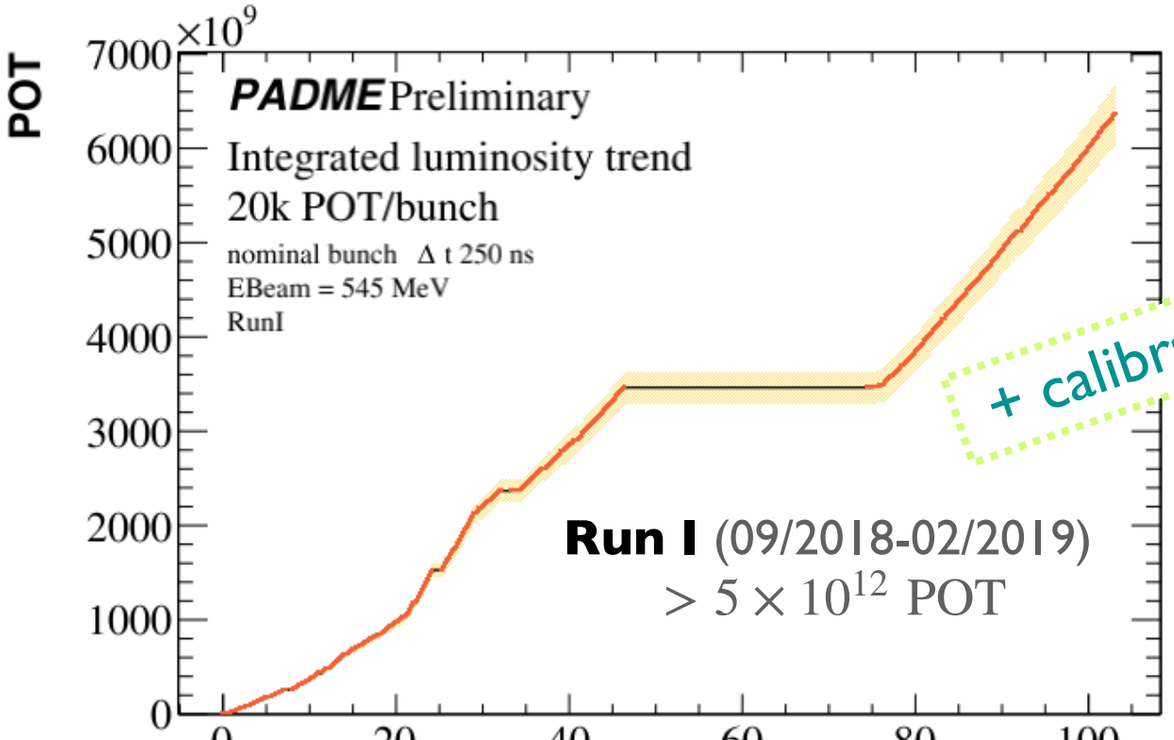




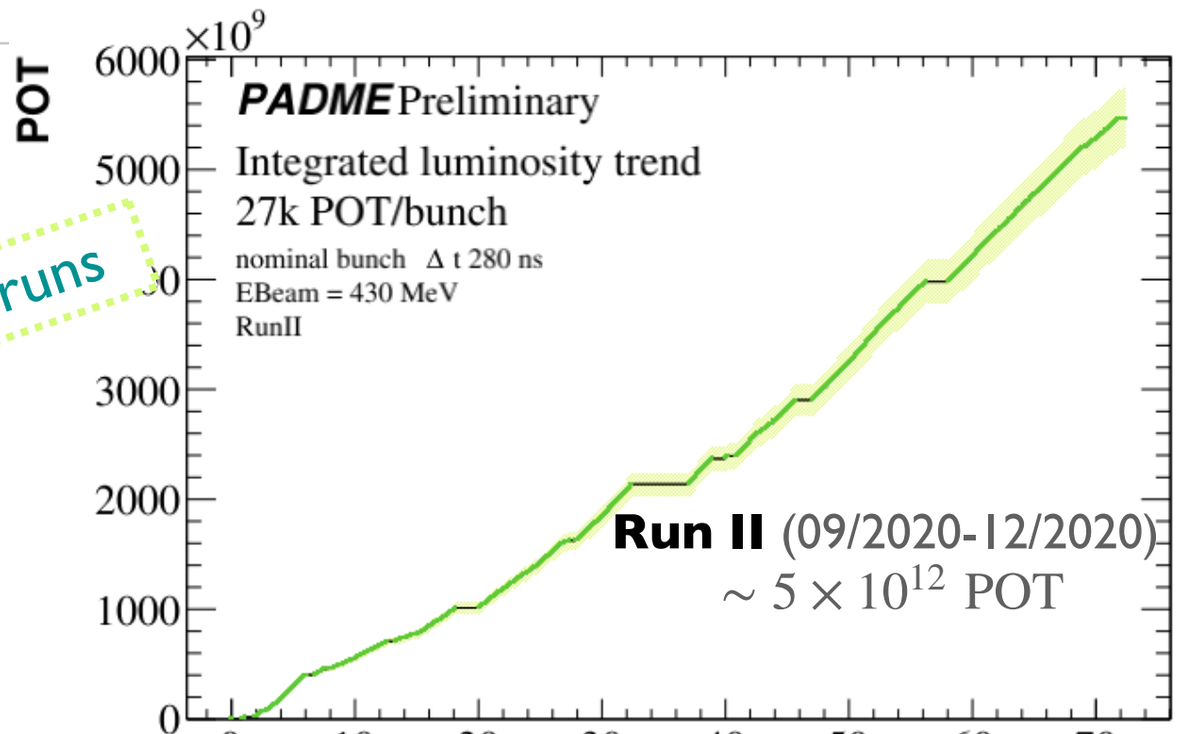
Experimental setup

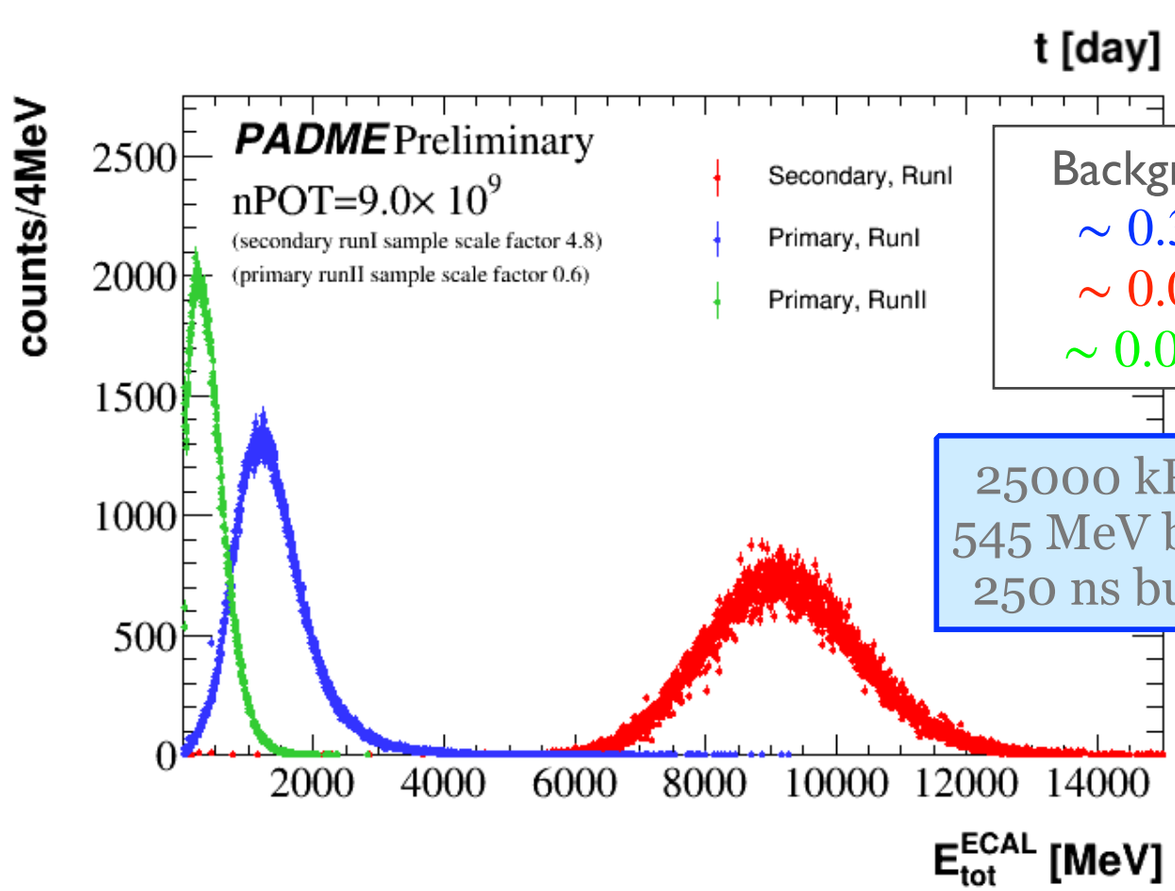
- LINAC e^+ beam: energy ≤ 550 MeV
- Diamond active Target: $2\ \text{cm} \times 2\ \text{cm} \times 100\ \mu\text{m}$
- Dipole magnet MBP-S: B ≤ 1.4 T
- Veto system: >200 plastic scintillator bars
- Main calorimeter ECAL: 616 BGO crystals
- Small Angle Calorimeter SAC: 25 PbF_2 crystals

PADME DATA TAKING



+ calibration runs





Background index:
~ 0.36 MeV/e^+
~ 0.03 MeV/e^+
~ 0.013 MeV/e^+

- Beam related background is observed
- Detailed beam line description in the MC used to investigate it
- Improving of the beam line → beam transportation

25000 kPOT/bunch
545 MeV beam energy
250 ns bunch length

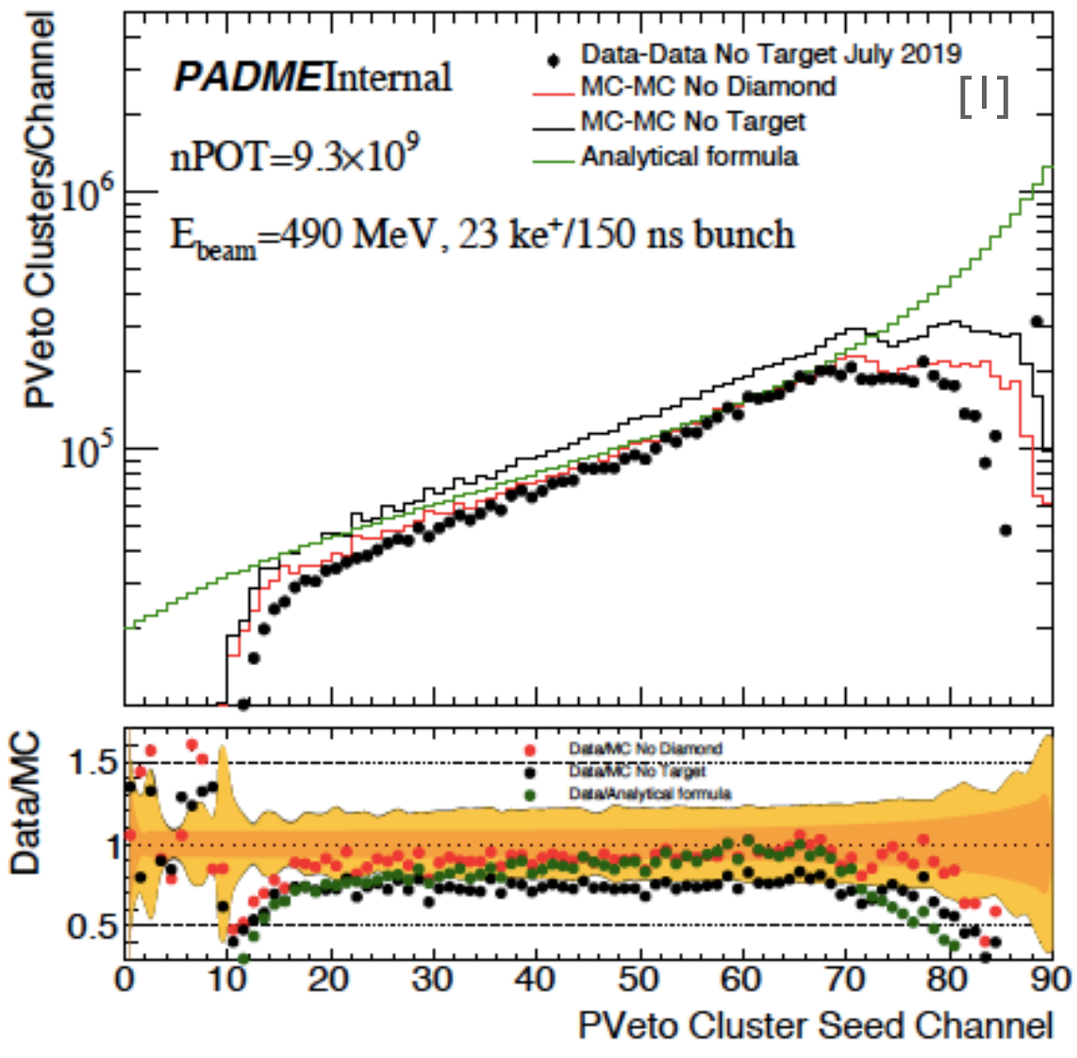
25000 kPOT/bunch
490 MeV beam energy
250 ns bunch length

28000 kPOT/bunch
430 MeV beam energy
280 ns bunch length

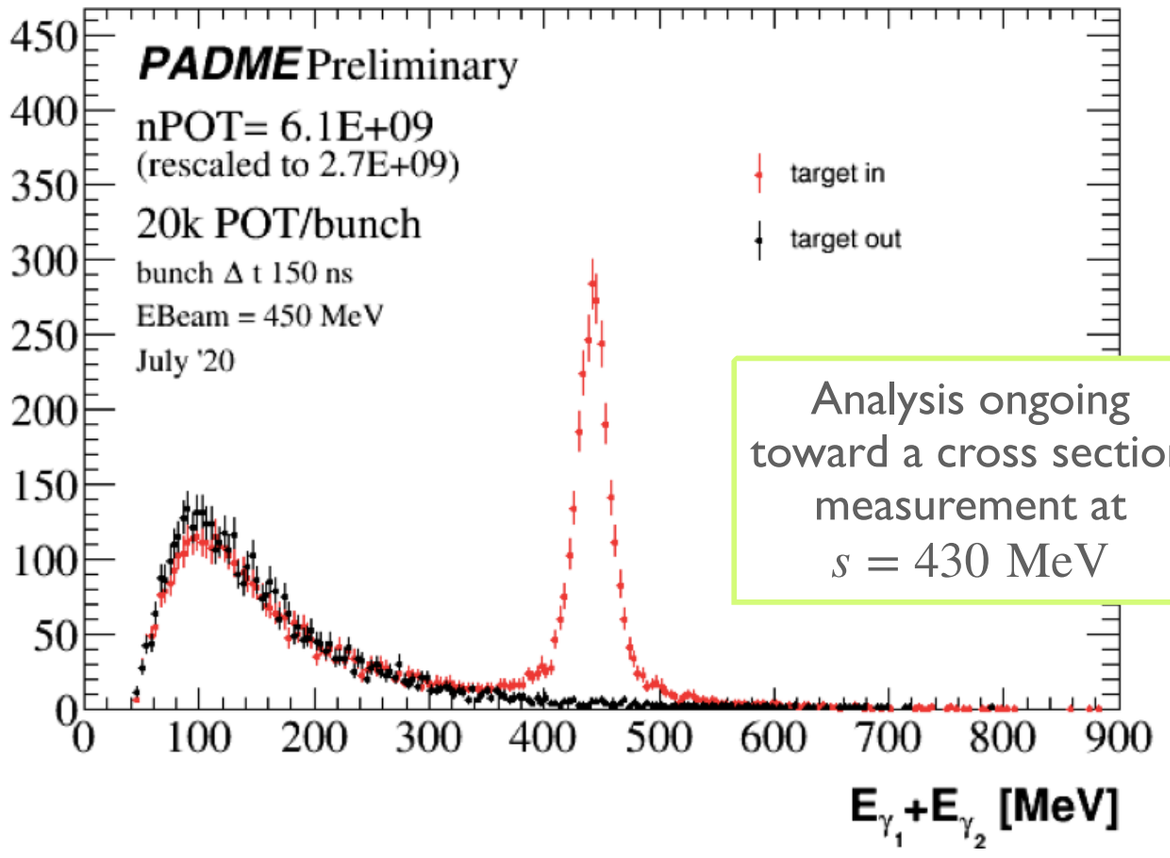
SM PROCESSES IN PADME

$e^+N \to e^+N\gamma$

Bremsstrahlung positron profile on PVeto estimated by subtracting data with target and without target in data and MC compared to analytical formula (PDG)



$e^+e^- \to \gamma\gamma$



Analysis ongoing toward a cross section measurement at $s = 430$ MeV

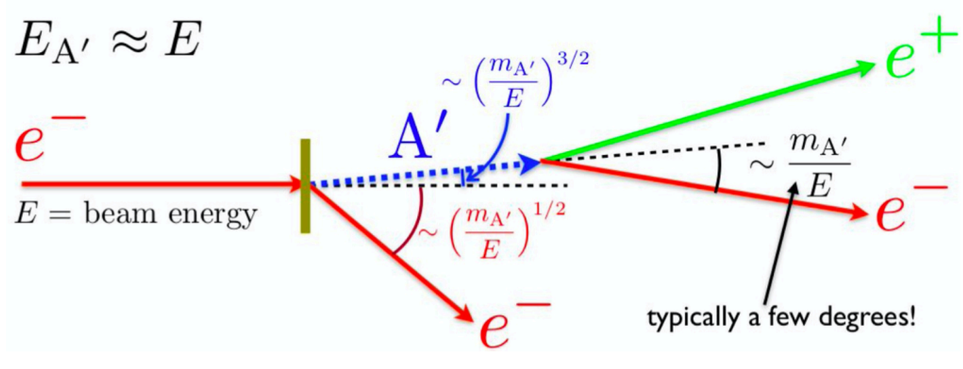
Annihilation spectrum in the main calorimeter for a standard run configuration (red) and in a special one (black). The improvements on the beam line and in the ECAL reconstruction allow to have a negligible background

Dark sector search

- PADME
- HPS
- BDX
- POKER
- JPOS

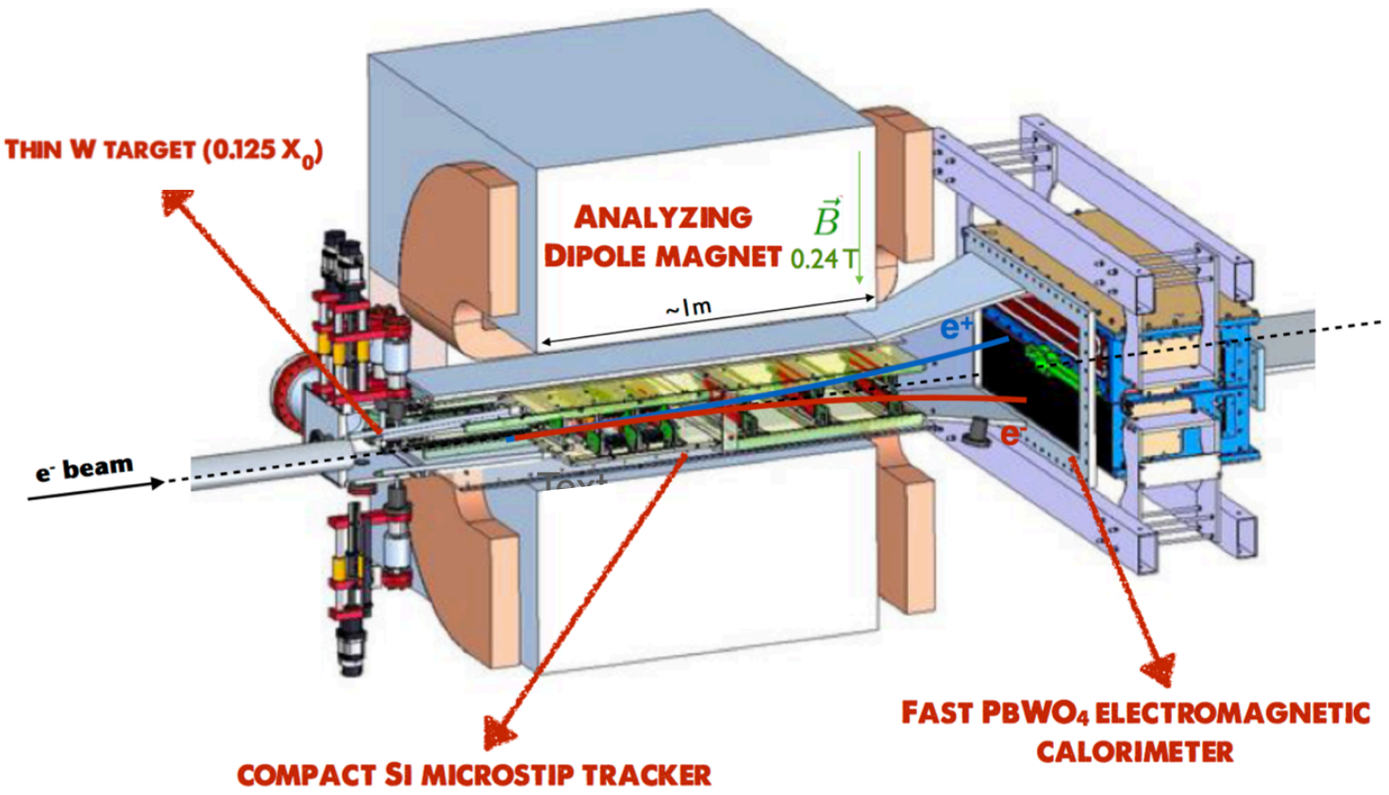
HEAVY PHOTON SEARCH - HPS @ JLAB

- e^- fixed target experiment installed in JLAB-HALL B searching for dark photons in the mass range 19 MeV - 500 MeV



Experimental setup

- CEBAF e^- beam: energy (1.1 - 6.6 GeV) current (50 nA - 500 nA)
- Thin W target
- Dipole magnet and 6-layers Si-tracker for momentum analysis and vertexing
- $PbWO_4$ calorimeter for triggering and PID



LDM detection

- Heavy photon signatures:
  - Resonant search
  - detached vertex search

HPS STATUS

- In 2014 PAC41 selected HPS for “High Impact Status”
  Beam time approved: 180 PAC days
- Spring 2015: 1.7 PAC days @ 1.06 GeV. Results published in PRD rapid communications
- Many measurement campaigns at different beam energies
- HPS is currently running. It will be take data for about 2 months using a e^- beam @ 3.8GeV

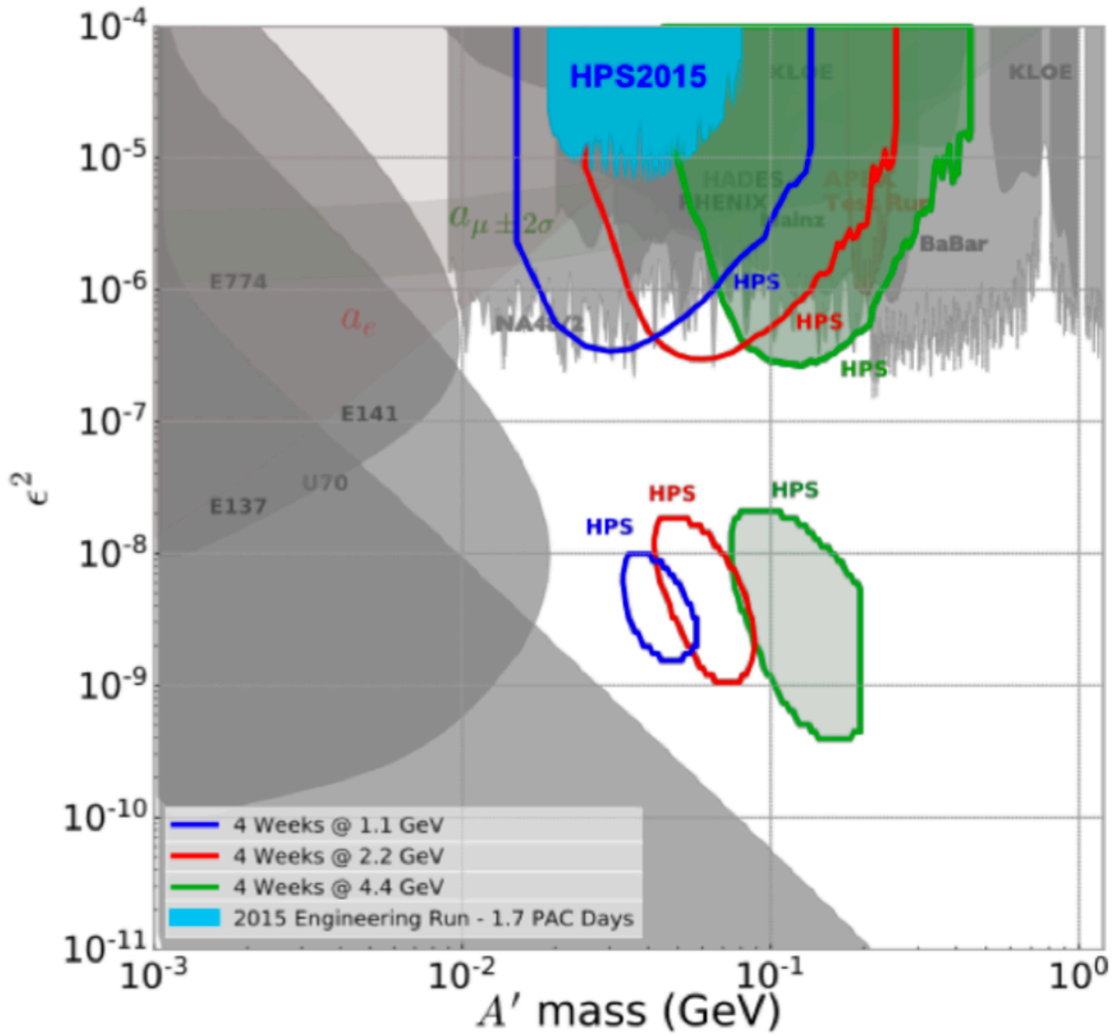
PHYSICAL REVIEW D **98,** 091101(R) (2018)

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)



Dark sector search

- PADME
- HPS
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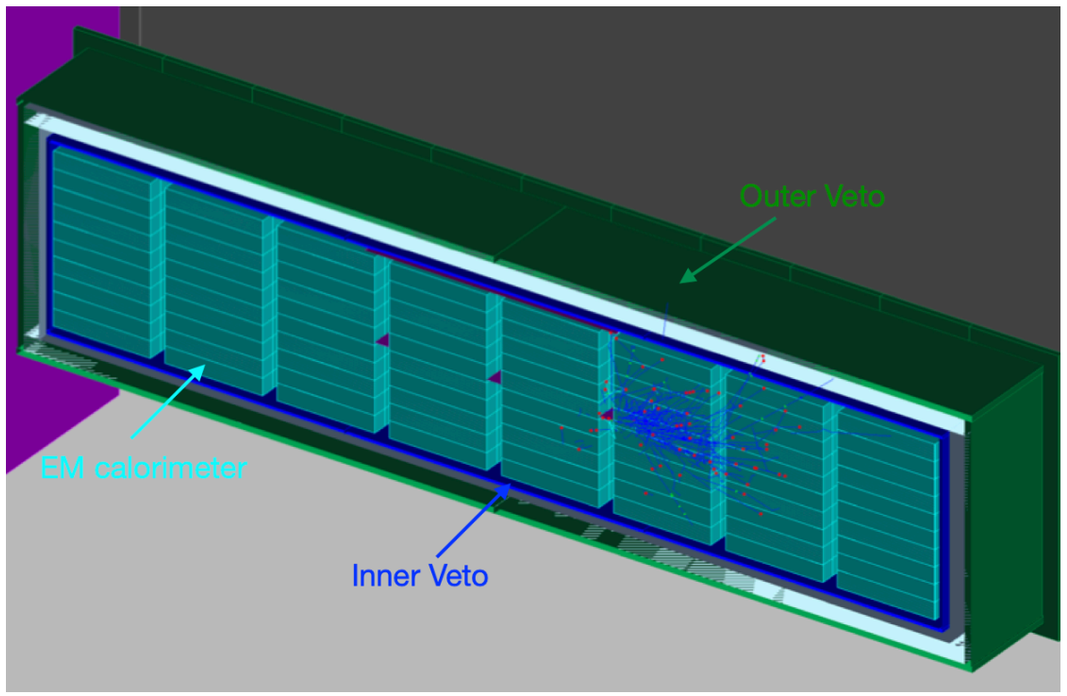
BEAM DUMP EXPERIMENT- BDX @ JLAB

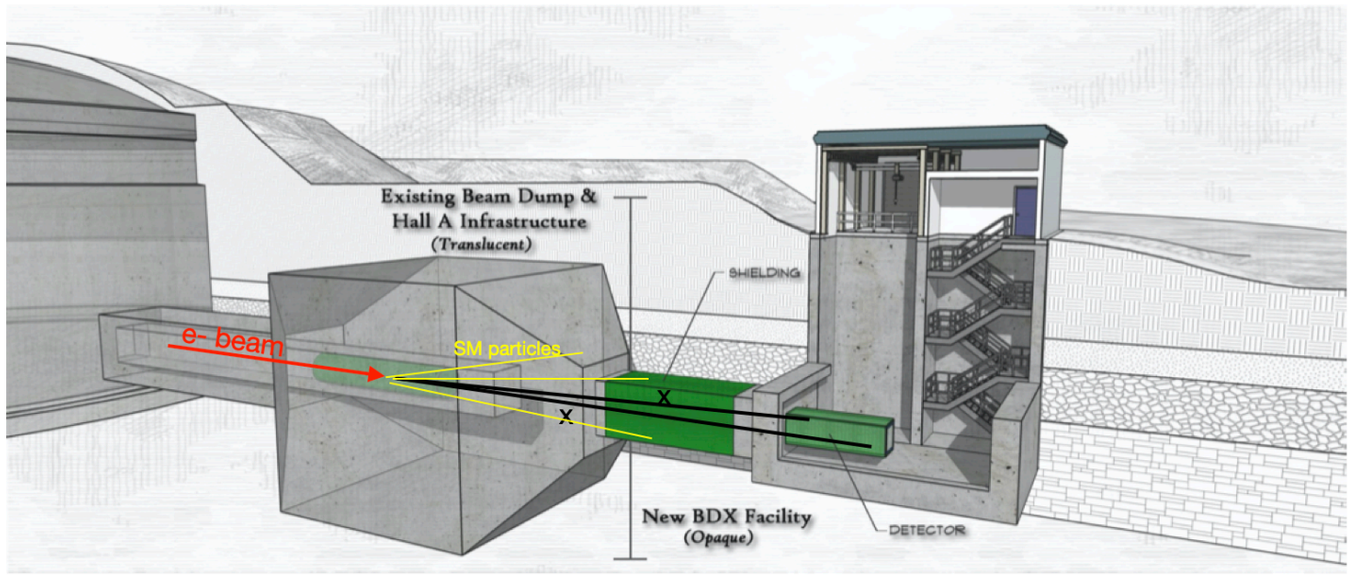
LDM production

- High-intensity e^- beam impinging on a thick target
- Secondary X particles produced through all previously discussed physics reactions

LDM detection

- Detector placed behind the dump
- X scattering through A' exchange, recoil releasing visible energy





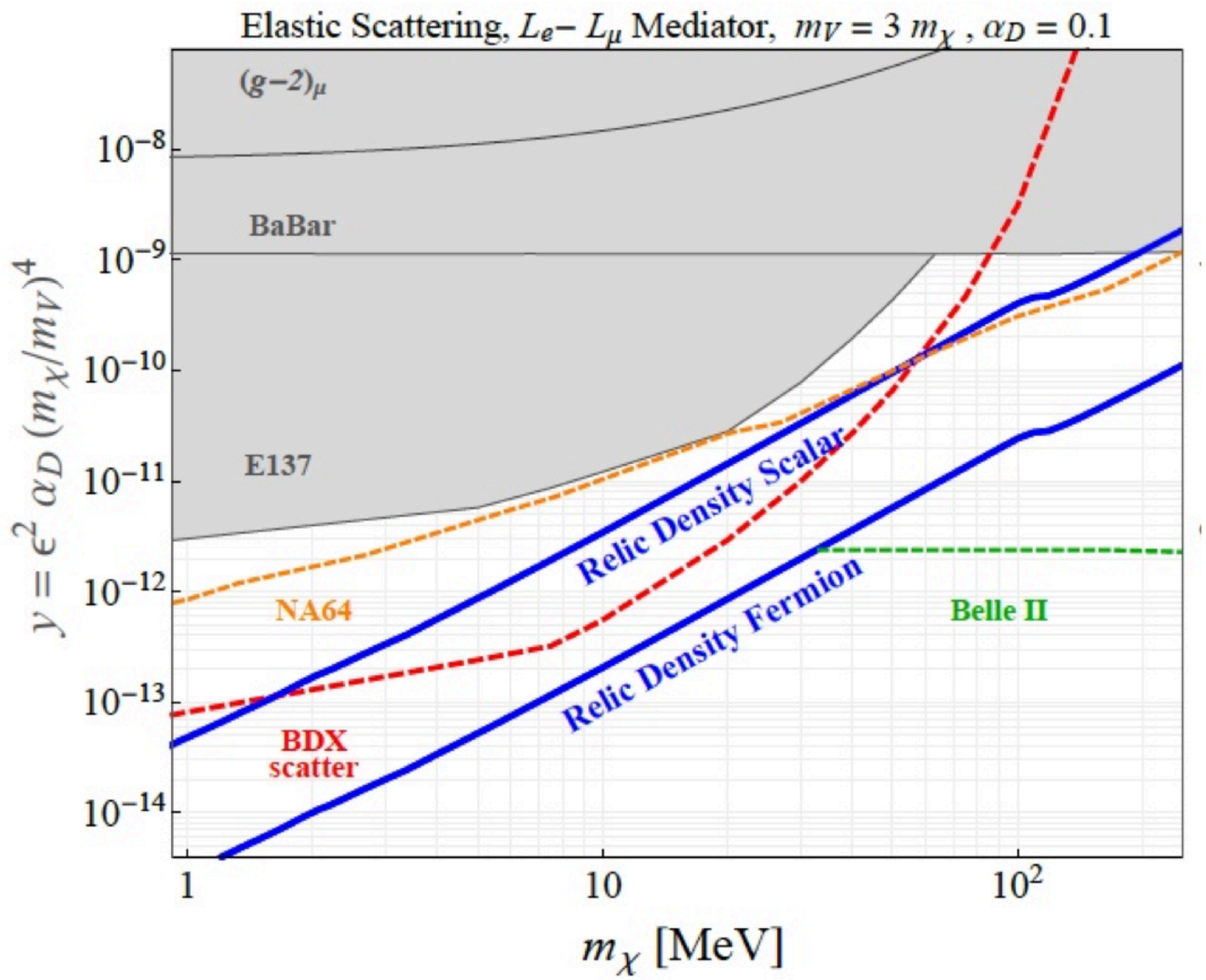
Experimental setup

- High-intensity (~65 uA) 11 GeV CEBAF e^- beam impinging on the HALL A beam dump
- Passive shielding layer between BD and detector to reduce SM beam-related background
- BDX detector (~1 m^3 active volume):
  - Homogeneous EM calorimeter made with CsI(Tl) crystals and SiPM readout.
  - Veto system: two layers of plastic scintillator counters made of paddles, each read by WLS+SiPM

BDX @ JLAB

BDX sensitivity

- With $O(10^{22})$ 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 experiments



BDX status

- Full proposal approved by JLAB PAC46 with the highest scientific rating.
- Currently discussing with laboratory management to build the new experimental hall
- A reduced version of the detector, BDX-MINI, deployed by the BDX collaboration, **performing a first search for LDM**. (see M. Spreafico talk)
  - Despite the reduced size of the experiment, the physics reach expected will set exclusion limits comparable to previous experiments

Dark sector search

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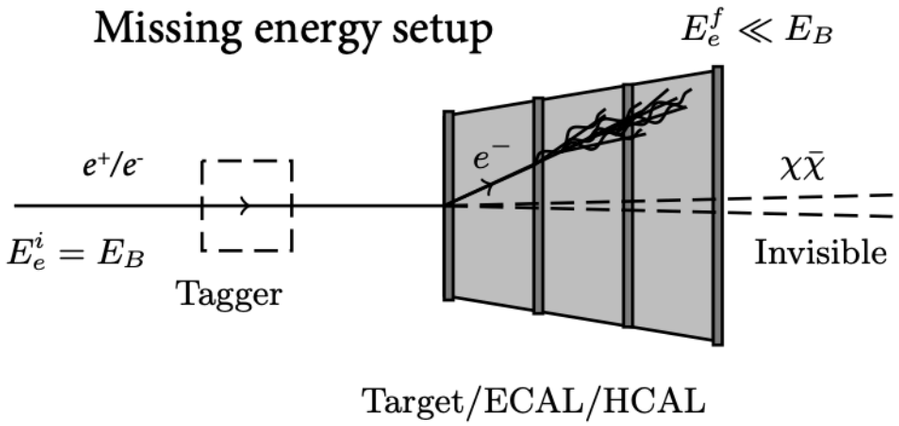
POSITRON RESONANT ANNIHILATION INTO DARK MATTER: POKER @ CERN

- Missing-energy active thick-target search with high-energy positrons
- Exploit resonant LDM production

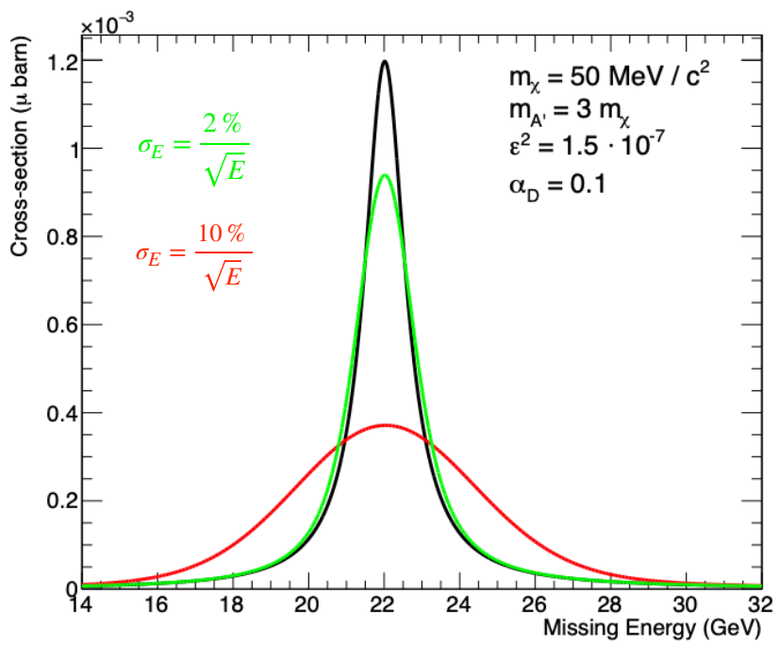


Missing energy experiment:

- The detector acts as an active thick target
- Deposited energy E_{dep} measured event-by-event
- Signal: large $E_{miss} = E_{beam} - E_{dep}$

Key POKER idea:

- Positron beam
- Signal production reaction: $e^+e^- \rightarrow A' \rightarrow \chi\chi$
- **Signature**: Missing energy distribution shows a peak around $E = M_{A'}^2/2m$



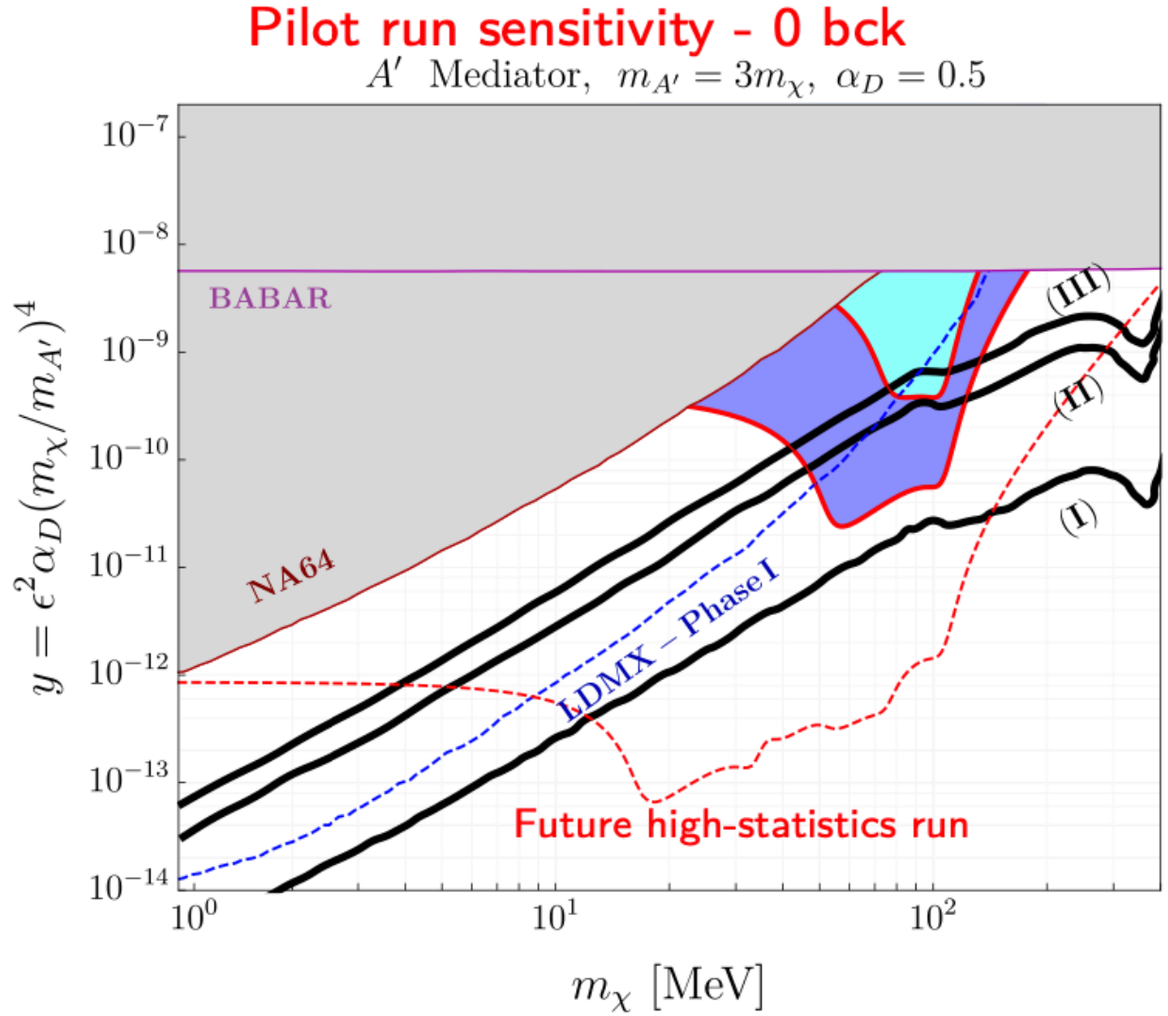
POKER @ CERN STATUS AND PROSPECTIVE

- **POKER timeline:** 5-years ERC project starting in December 2020
- **POKER goal** : perform a pilot run experiment at CERN H4 beamline accumulating at least 5×10^{10} POT

European Research Council
Established by the European Commission

POKER strategy

- Beam: H4 beamline at CERN
  - 100 GeV e+ with 1e+/μs
- Synergy with NA64 experiment:
  - Exploit the NA64 beam tagging and diagnostic devices
  - re-use the existing NA64 hadronic calorimeter
- **Active target**: design and construct an optimised, high-resolution EM calorimeter



Dark sector search

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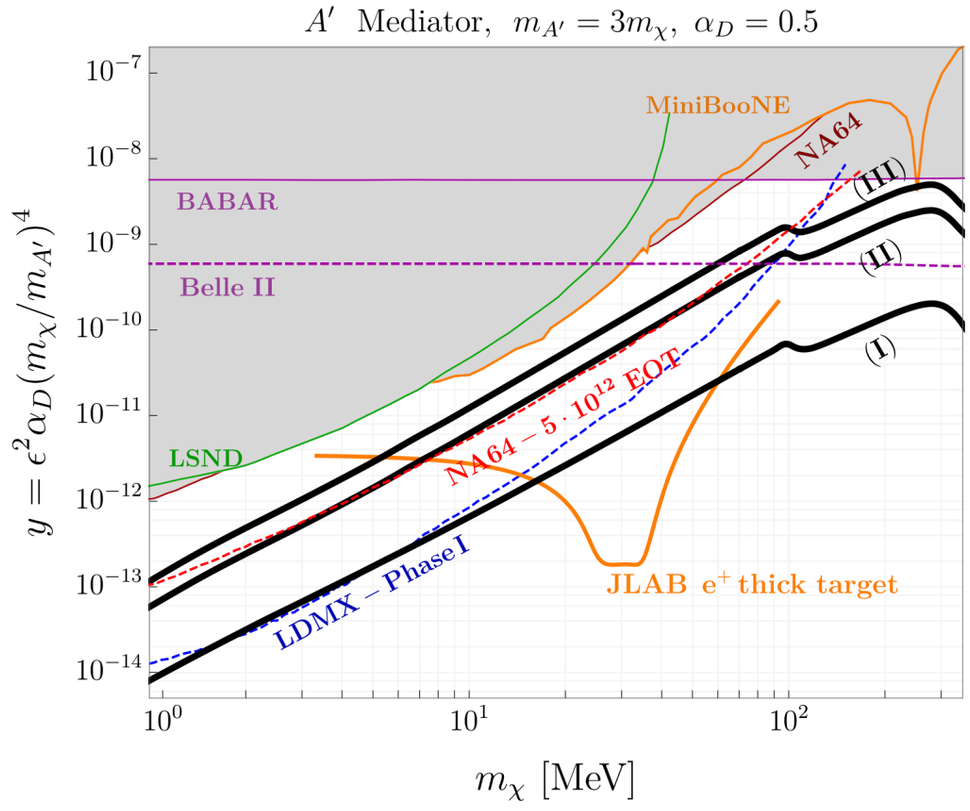
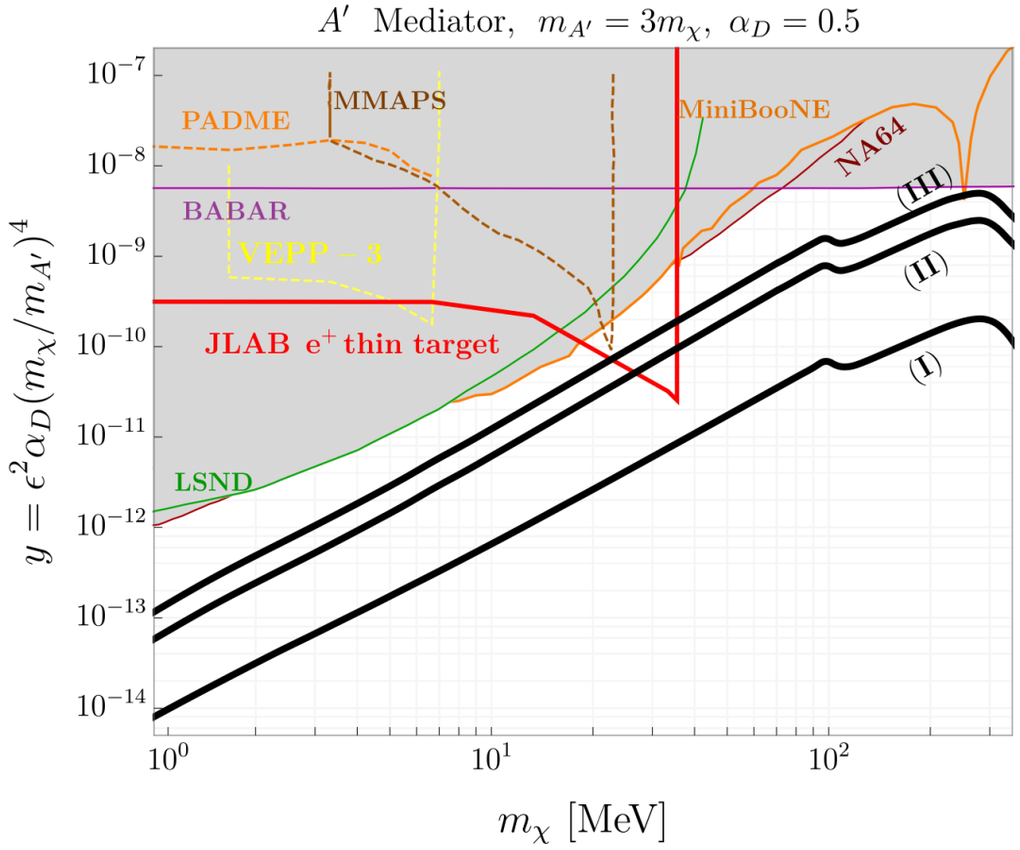
JPOS: FUTURE INTENSE 11GEV-POSITRON BEAM AT JLAB

- Thin-target experiment (PADME-like)
- A' produced through: e+e- -> γA'
- Final state photon detected in EM-Calorimeter; A' reconstructed by missing mass technique
- Signature: peak in the missing mass distribution





- Thick-target experiment (missing energy)
  - (see P. Bisio talk)
- A' produced through: e+e- -> A'->XX
- Signal events are identified when the missing energy E_{miss}, exceeds a minimum threshold value.
- Signature: peak in the missing energy distribution, at a value depending solely on the A' mass.

The unique properties of this facility will allow these two experiments to investigate vast unexplored regions in the parameters space, beyond those covered by current or planned experiments.

CONCLUSION

- Cosmological and astrophysical anomalies motivate the introduction of new matter in the Standard Model
- A possibility is to add a new Gauge Symmetry to describe the dark matter which imply a new massive Gauge boson A’
- Accelerator-based (Light)DM search provides unique feature to probe the existence of DM
- Many opportunities for experimental exploration and discovery fixed target experiments searching for LDM with orders of magnitude more sensitivity
- Extensive experimental plans at high intensity e+/e- facility: LNF, JLab, Cornell, Mainz, SLAC, CERN