

Future Dark Sector Searches at Jefferson Lab

People have always been fascinated by what is hidden from their view

Patrick Achenbach

Johannes Gutenberg University Mainz

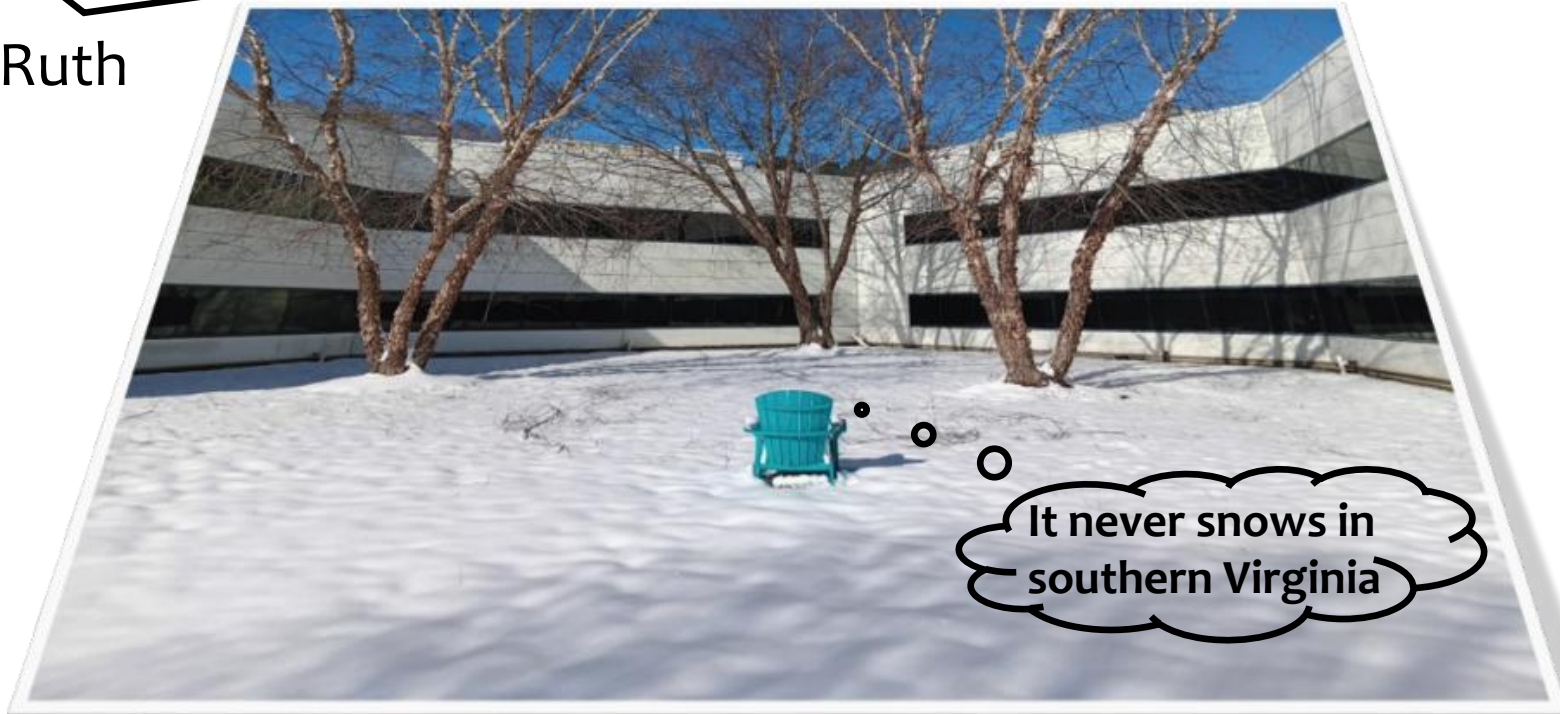
*Jefferson Lab User Organization Board of Directors Vice-Chair
(Jefferson Lab Physics Division Leadership Team until 9/2025)*

Sept. 2026

Why I am Here at this Workshop

“... Hauptsächlich sind wir neugierig, wie die Möglichkeiten für ein LDM-Experiment (LDMX oder etwas Ähnliches) in der Zukunft aussehen. ...”

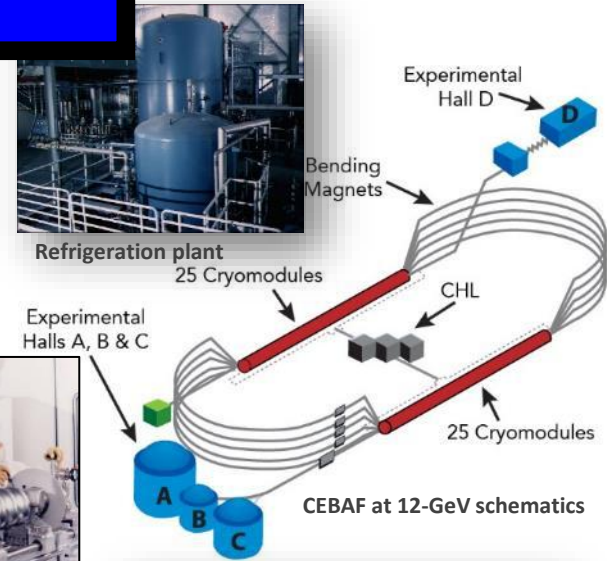
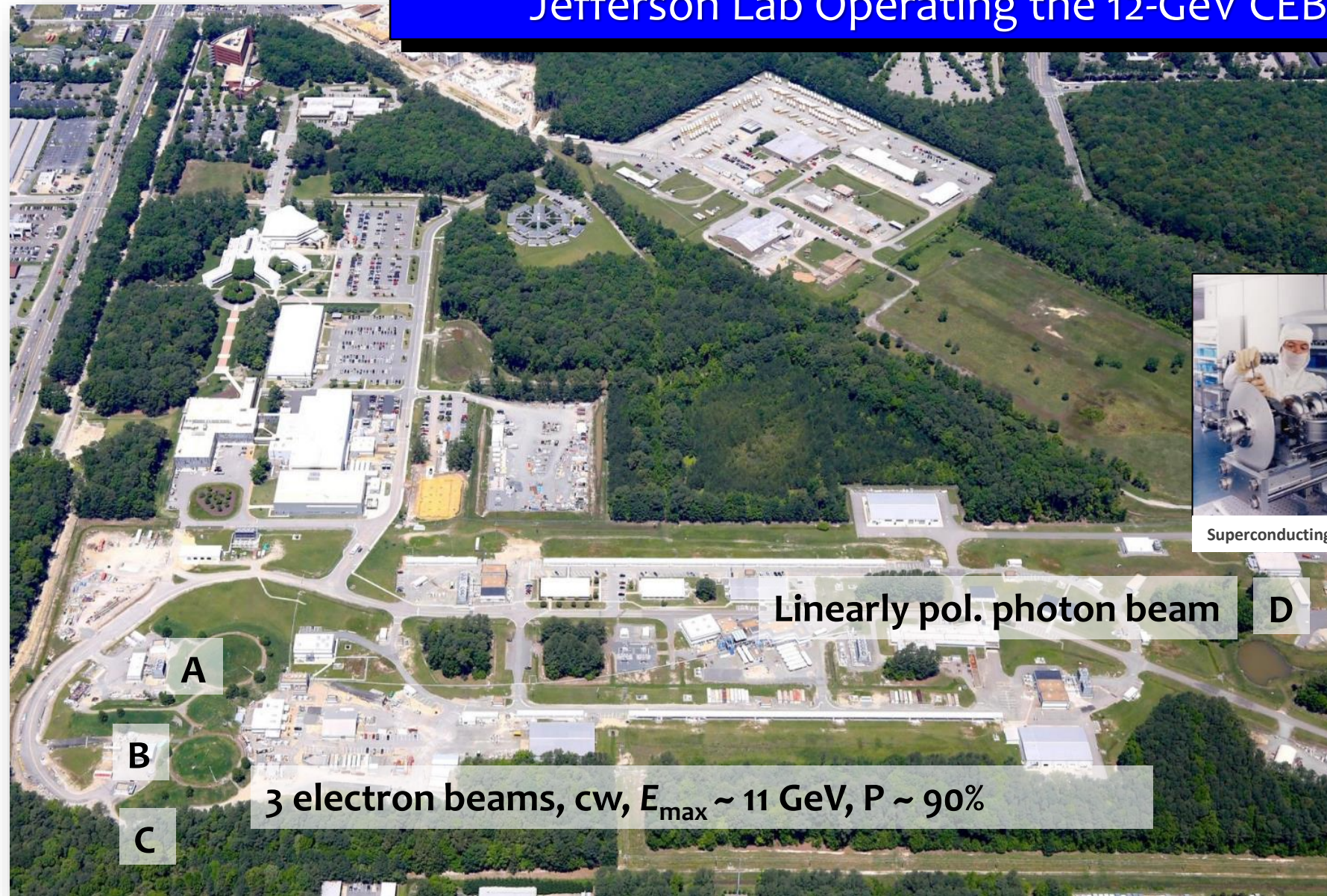
Ruth



→ Presenting my view on Jefferson Lab
(but not predicting Jefferson Lab's future)

CEBAF

Jefferson Lab Operating the 12-GeV CEBAF



Superconducting niobium RF cavities



Cryomodules in the accelerator tunnel



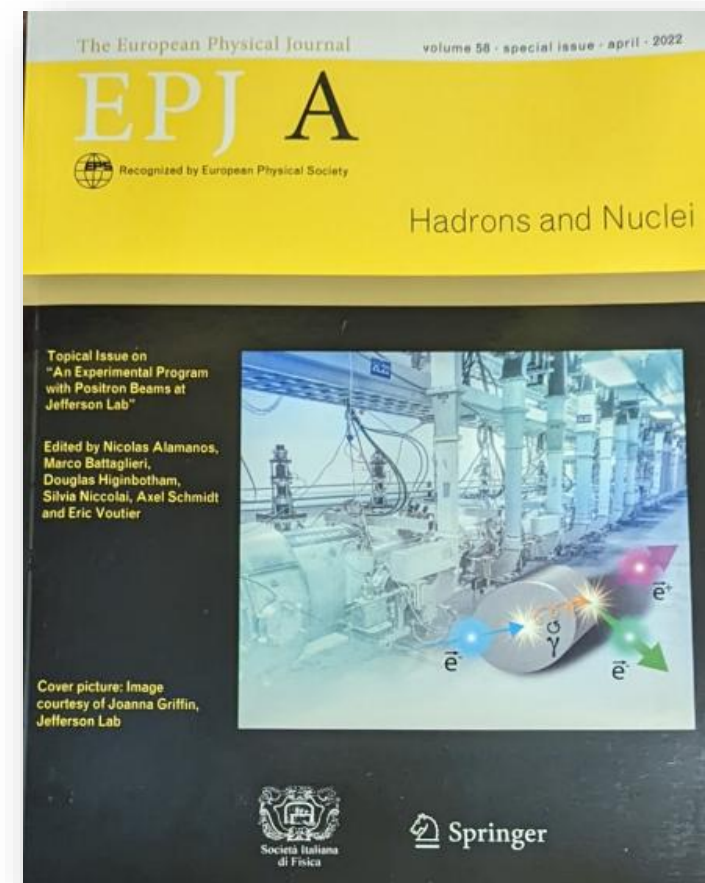
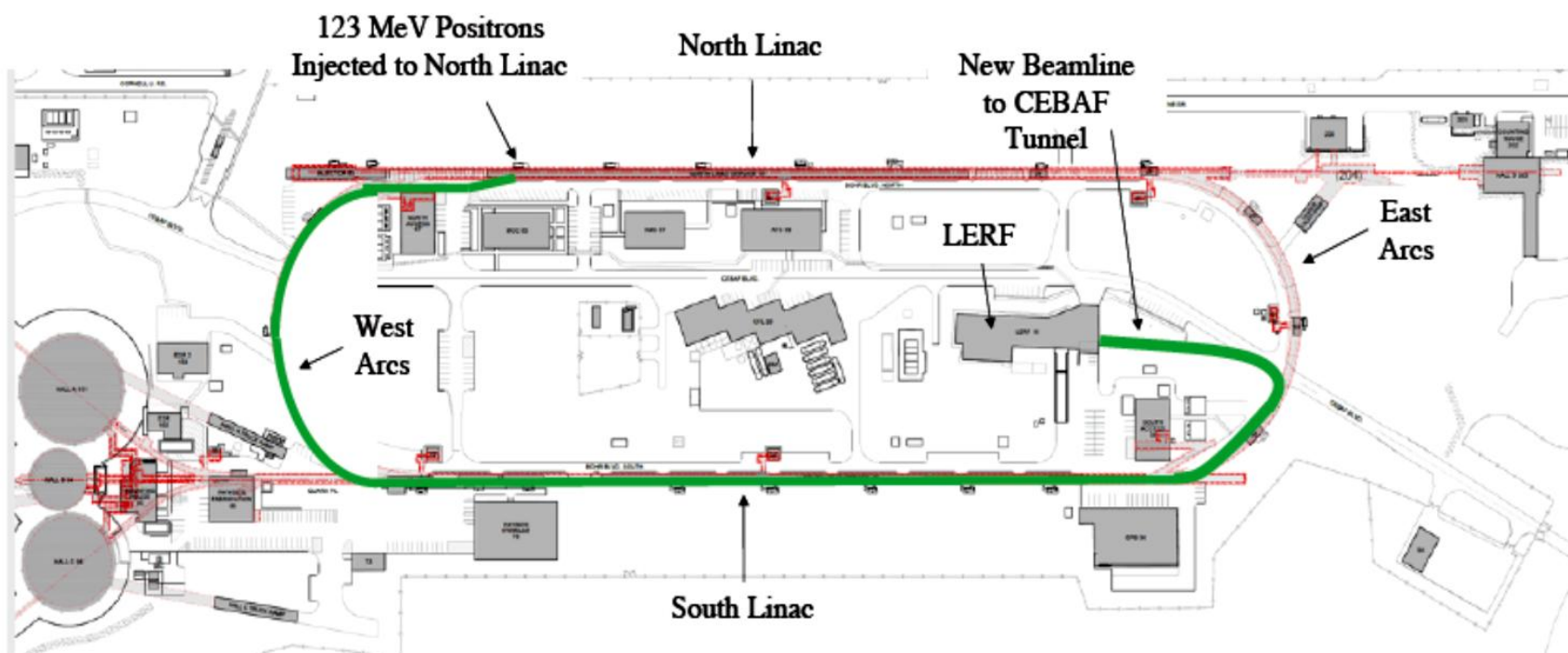
Recirculation arcs

[P.A. Adderley et al., Phys. Rev. Accel. Beams 27 (2024) 084802, doi: 10.1103/PhysRevAccelBeams.27.084802]

CEBAF Upgrade to 11-GeV Positrons (Ce+BAF)

Polarized positrons produced in former FEL (“LERF”)

- Transport to CEBAF for positron acceleration up to **11 GeV**
- High duty factor beams with intensities up to 1 μA
- Several approved PAC proposals, mostly Halls B and C

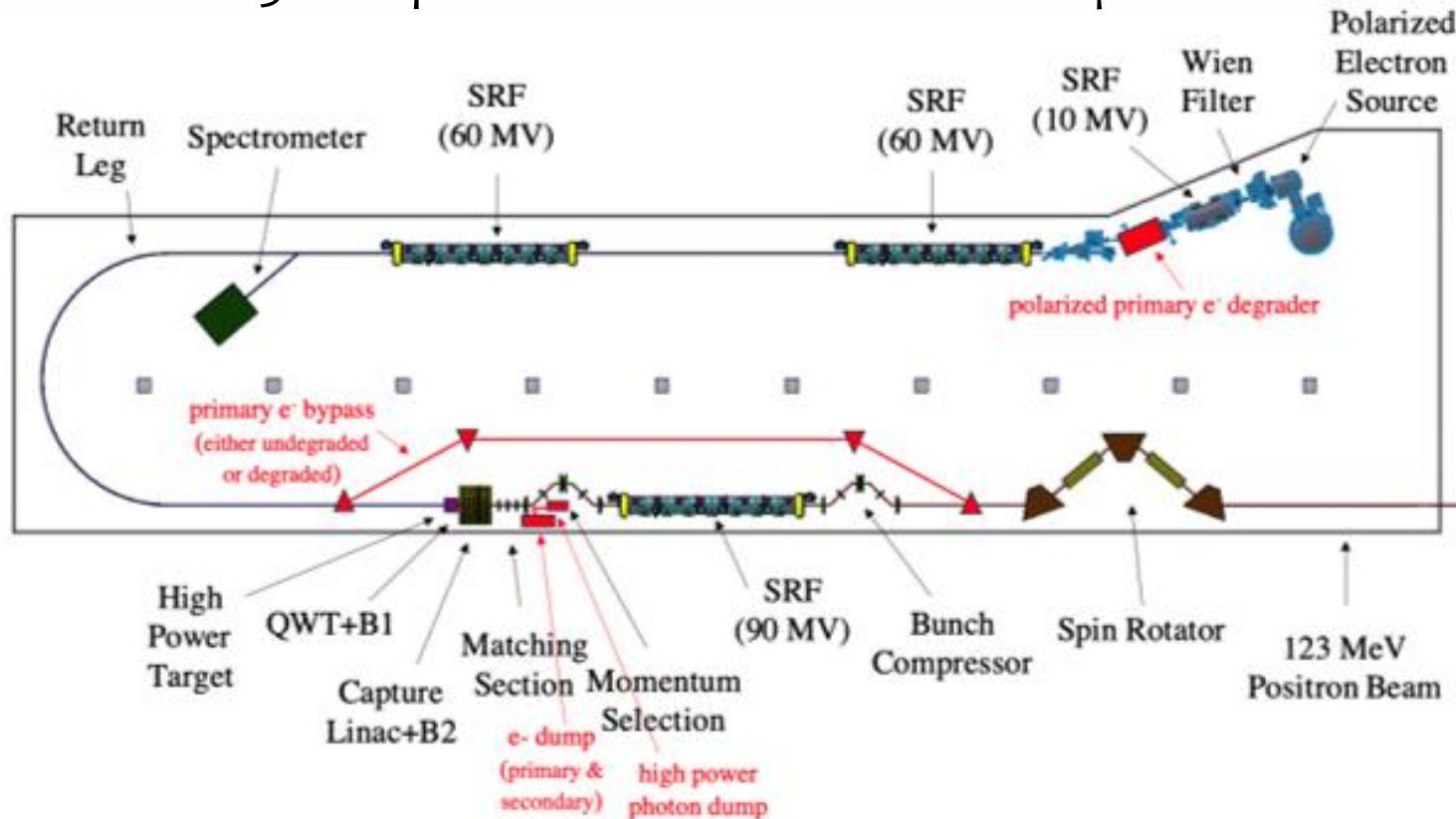


[N. Alamanos, M. Battaglieri, D. Higinbotham et al., *Topical issue on an experimental program with positron beams at Jefferson Lab*, Eur. Phys. J. A 58, 45 (2022), doi: [10.1140/epja/s10050-022-00699-6](https://doi.org/10.1140/epja/s10050-022-00699-6)]

CEBAF Upgrade to Low-Energy Electrons/Positrons

Ce+BAF requires a new injector that will create new research opportunities

- ~ 10 MeV electron beams with ~ mA current
- ~ 120 MeV electron beams with ~ mA current
- 123 MeV positron beams with ~ nA to ~ μ A current

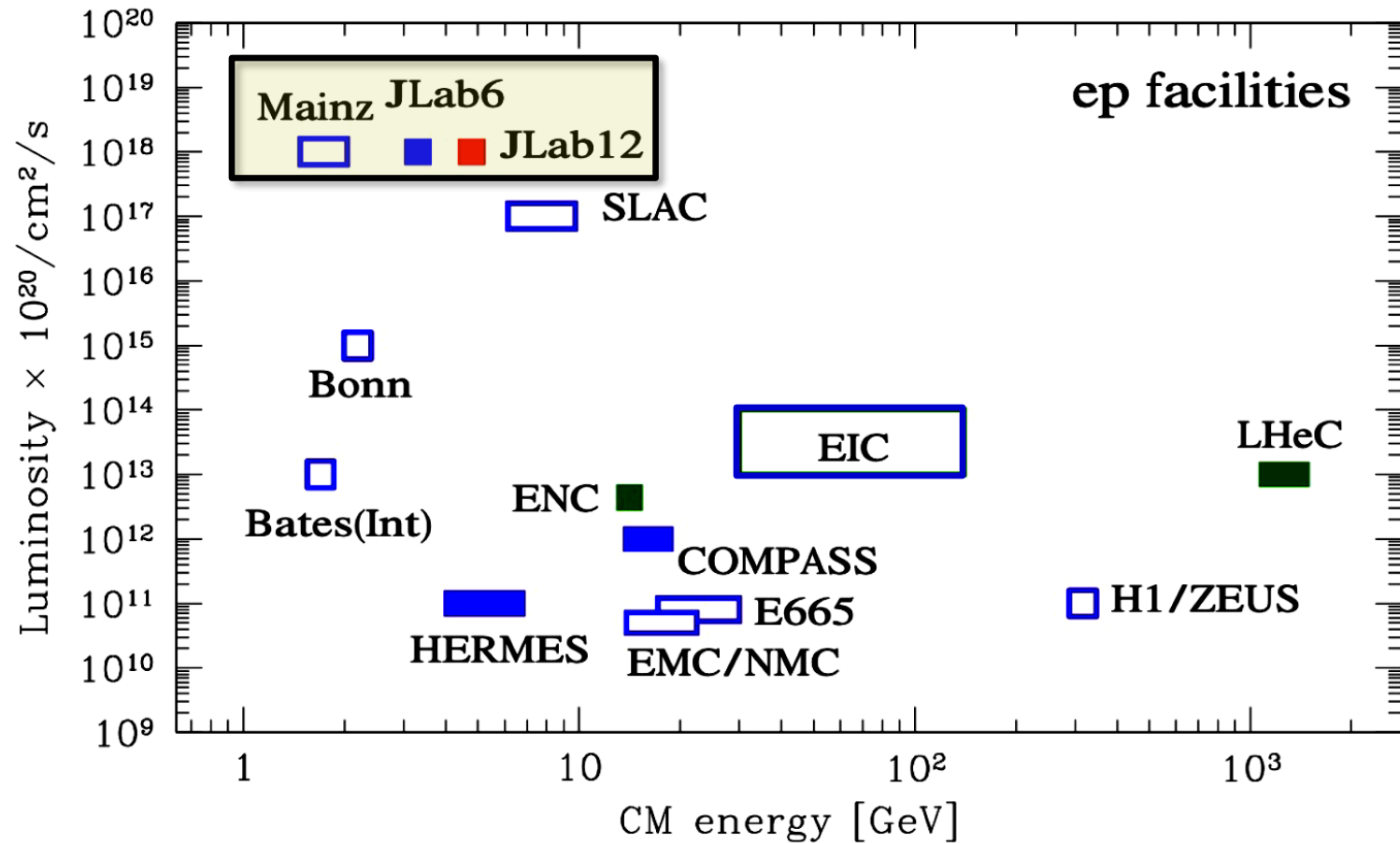


**LOW ENERGY
ELECTRON
POSITRON PHYSICS
INTERNATIONAL
WORKSHOP** LEEPP@JLab

Newport News, VA, USA
March 23rd-27th, 2026!

<https://indico.jlab.org/event/964/>

Luminosities with MeV-to-GeV Electron Beams



MAMI A1/A4, MESA EB, and CEBAF Halls A/C positioned at the high-luminosity frontier ...

... but luminosity is only one of several aspects in dark sector searches

Dark Sector Experiments at Jefferson Lab

Dark Sector Searches at MeV-to-GeV Beams

Electron fixed-target searches

- Including beam dump expts.
- Including positron expts.
- Excluding e^+e^- collider expts. (BESIII, ...)
- Excluding older expts.
- Excluding meson-decay expts.

Expts. color code:

- **A' visible decay searches**
- **A' invisible decay searches**
- **Dark matter/sector searches**

Experiment

Past:

- **SLAC E137** (completed)
- **A1** (completed)
- **APEX** (completed)
- **BDX-MINI** (completed)
- **HPS/HPS** (partially completed)
- **PRad X17** (partially completed)
- **PADME** (completed?)

Near future:

- **HPS/HPS** (to be continued)
- **MAGIX/MAGIX** (in construction)
- **DarkMESA** (in preparation)

Further future:

- **BDX** (approved, needs infrastructure)
- **A' Search** (conditionally approved)
- **Lohengrin** (in preparation)
- **LDMX** (in preparation)

Beam/Facility

e- at SLAC
e- at MAMI
e- at Jefferson Lab
e- at Jefferson Lab
e- at Jefferson Lab
e+ at Frascati

e- at Jefferson Lab
e- at MESA
e- at MESA

e- at Jefferson Lab
e+ at Jefferson Lab
e- at ELSA/Bonn
e- at SLAC

APEX Dark Photon Search Experiment

Bump search in invariant mass spectrum

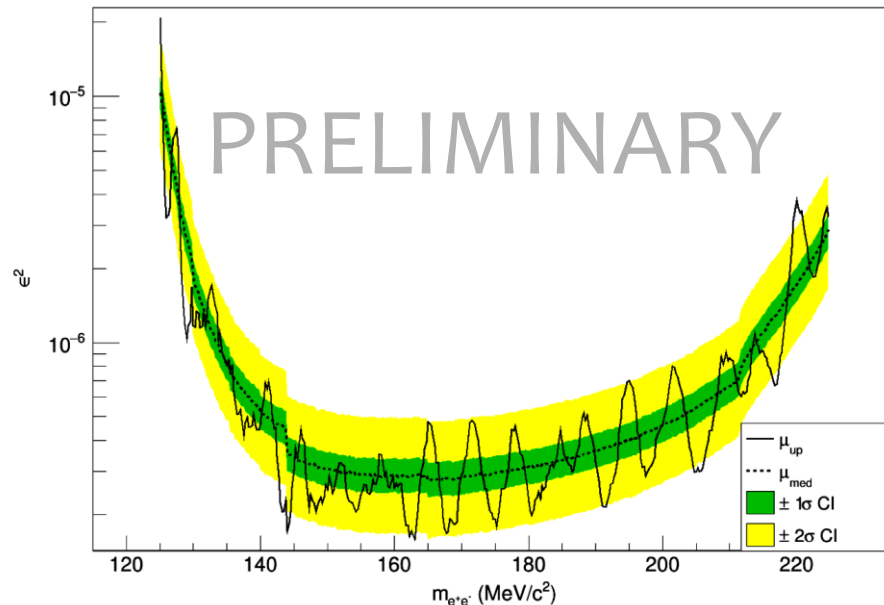
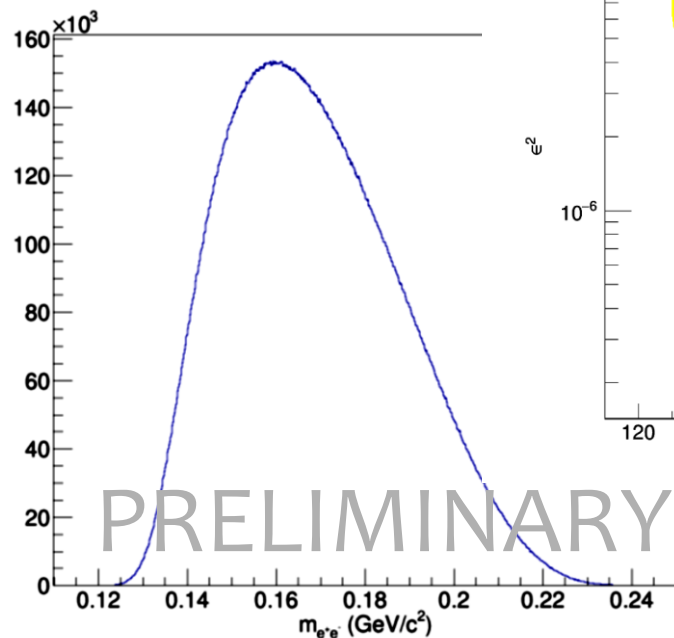
No. of reconstructed e^+e^- pairs:

$\sim 6 \times 10^7$ (8×10^5) events in 2019 (2010 test) run

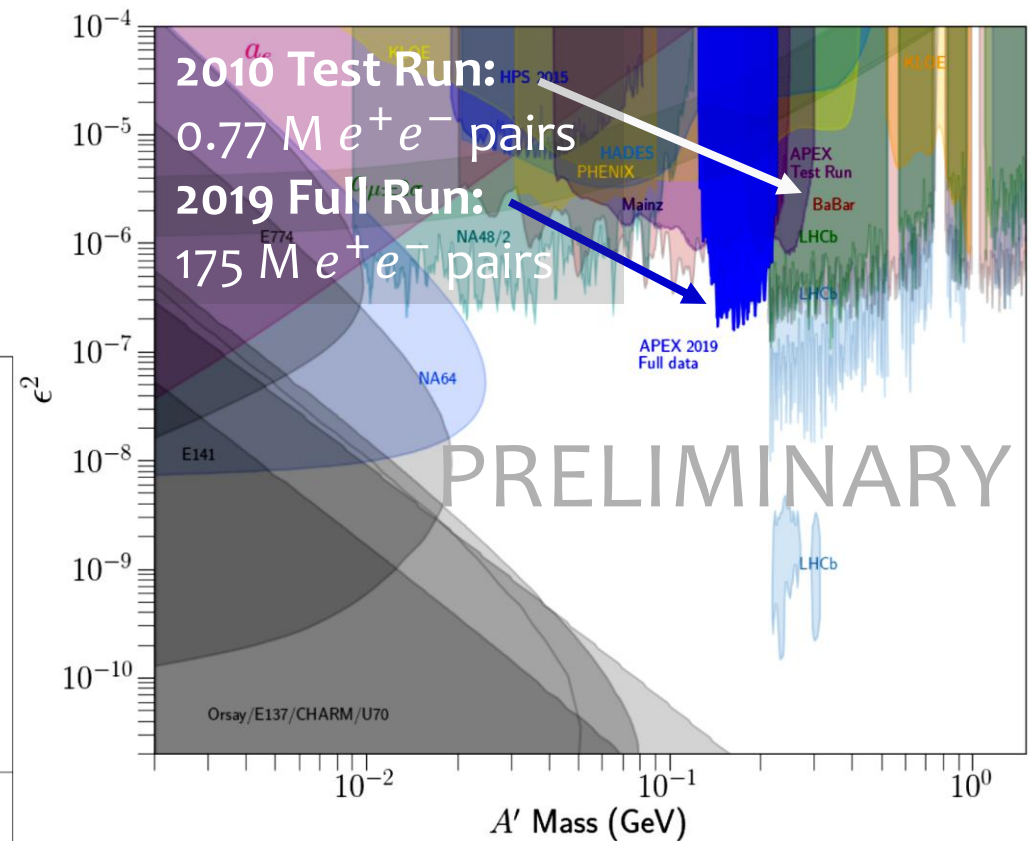
Test run result published

[APEX Collab., Phys. Rev. Lett. 107, 191804 (2011),
doi: 10.1103/PhysRevLett.107.191804]

Existing data



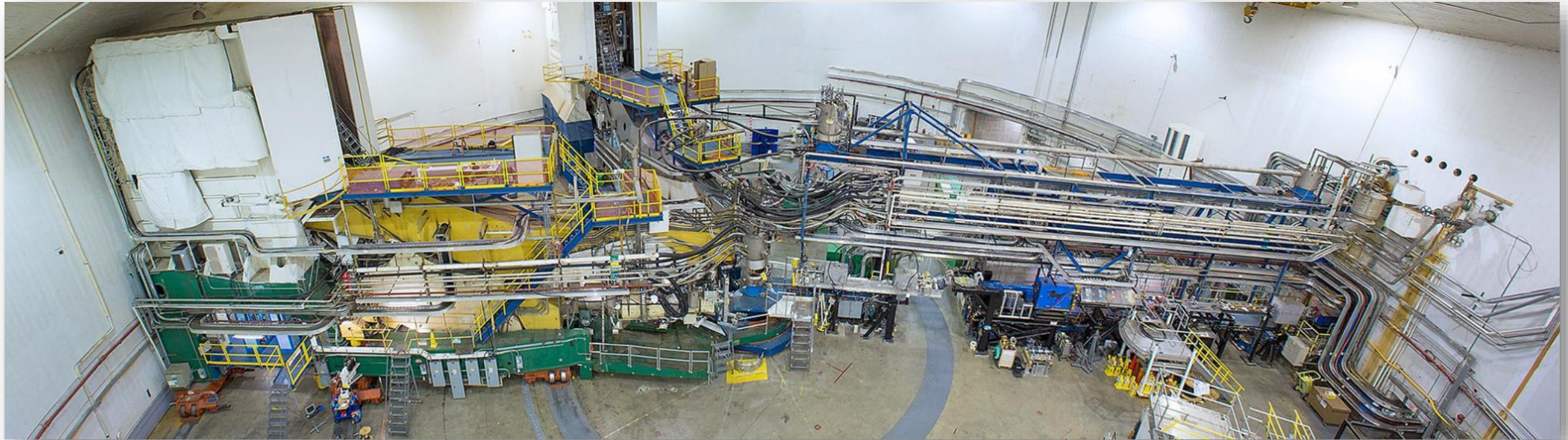
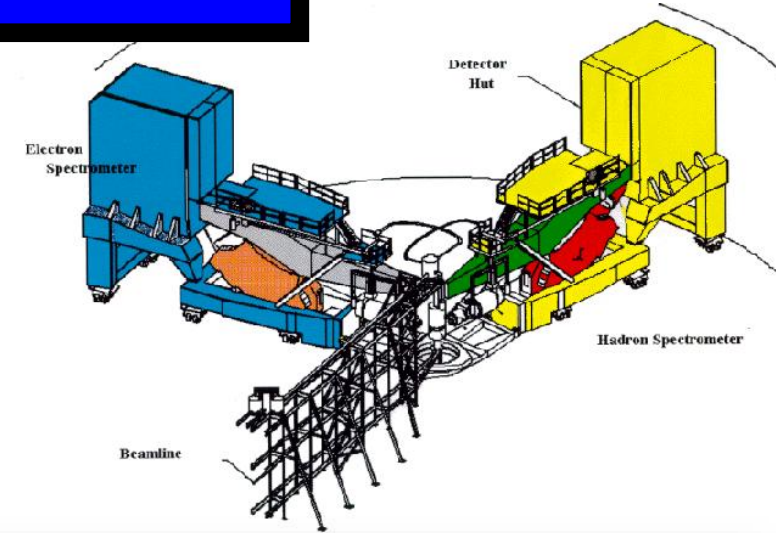
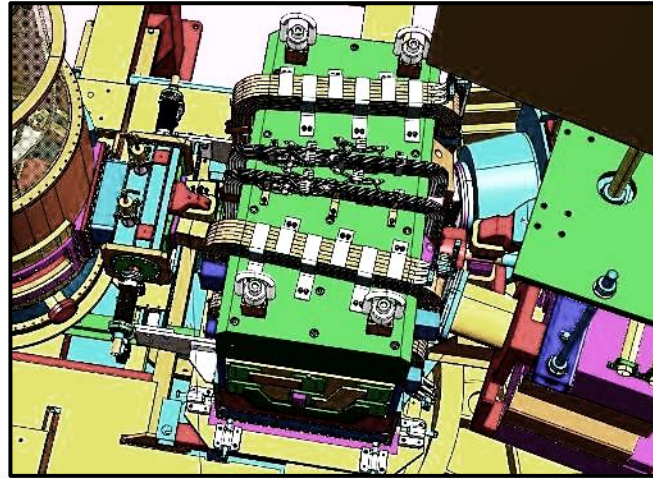
Exclusion limits



[R. Paremuzyan, LDMA Workshop (2025),
agenda.infn.it/event/43758/contributions/253043/attachments/134165/200678/LDMA_2025_Genova_Paremuzyan.pdf]

Setup for APEX in Hall A

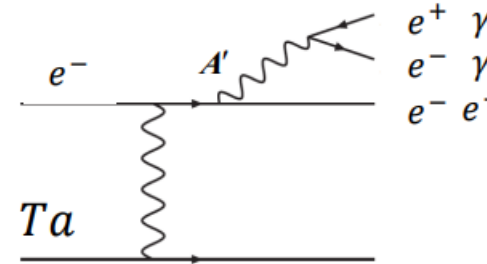
- Using two QQDQ High-Resolution spectrometers: Right and Left HRS
 - $\Delta p/p = 10^{-4}$, $\Delta\Omega = 6$ msr
 - Angular range $\theta = 12.5^\circ - 150^\circ$
Septum to access $\theta < 12.5^\circ$



X17 Search Experiment

A' electroproduction on heavy nucleus

- $e^- + Ta \rightarrow e' + X + Ta$



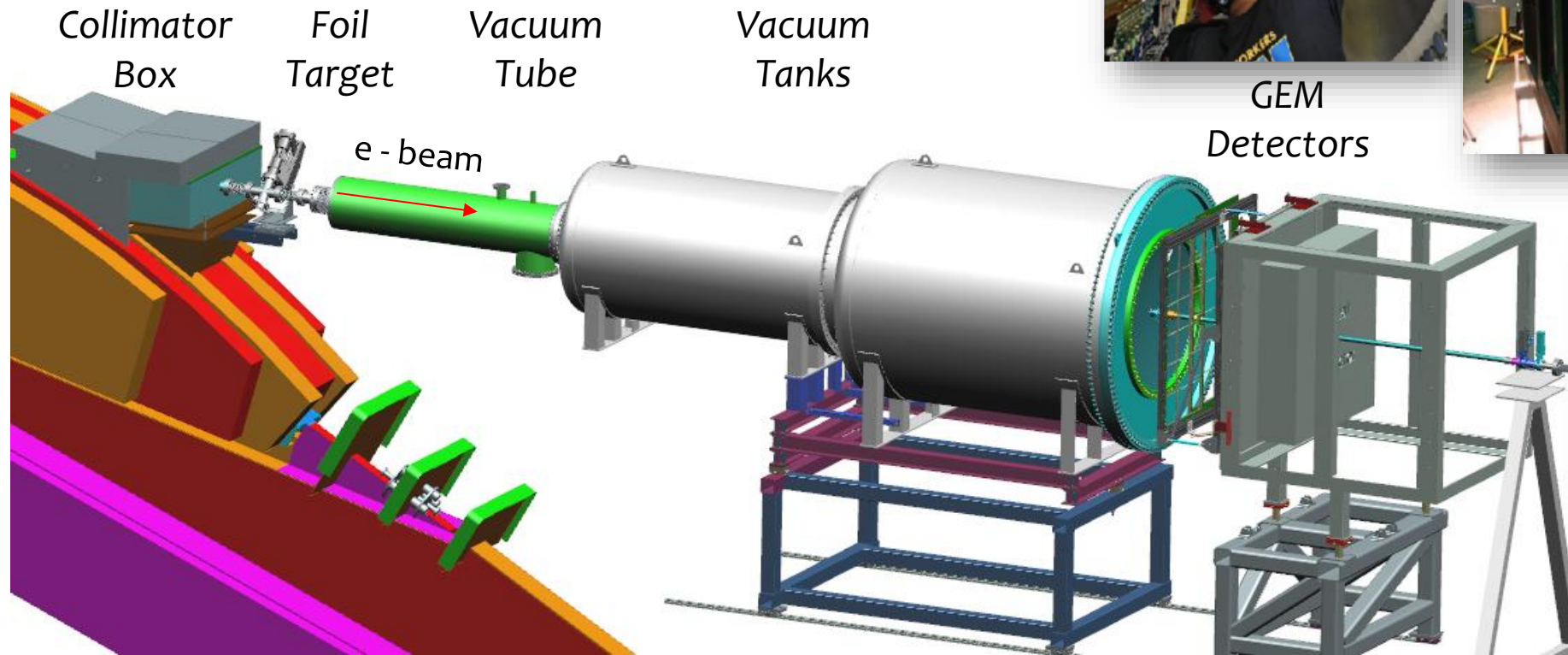
- **Detection of all final state particles** with 2 GEMs and PbWO₄ calorimeter
 - Scattered electron e' and decay e^+ and e^- from $X \rightarrow e^+e^-$
 - Scattered electron e' and decay $\gamma\gamma$ pair from $X \rightarrow \gamma\gamma$
- **Bump hunting** in invariant mass spectrum over SM background
- **Experiment performed in Spring 2026** and received 41% of approved time (completed 591 ABU hours or 24.6 PAC days)
- Experiment will **continue data taking in FY27** to reach at least 50%

Designed to exclude or validate X17 or other bosons
for masses **3 – 60 MeV/c²** and couplings $\epsilon^2 \approx 5 \times 10^{-7} - 10^{-6}$

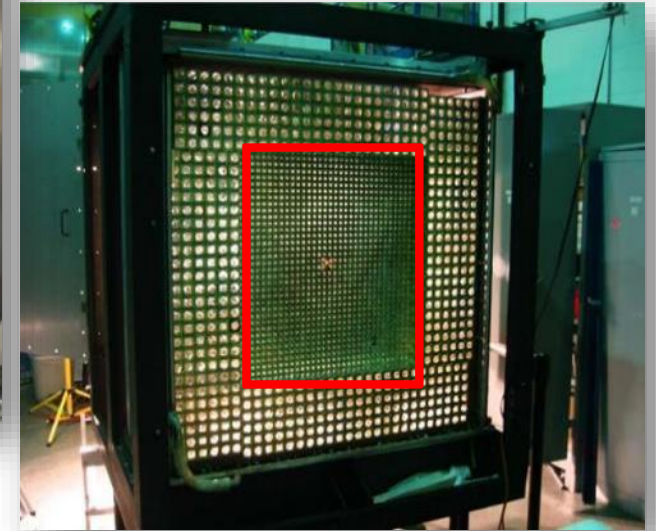
[A. Gasparian et al., accepted proposal PR12-21-003 at PAC49 (2021),
misportal.jlab.org/pacProposals/proposals/1759/attachments/152101/Proposal.pdf]

Setup for X17 Search in Hall B

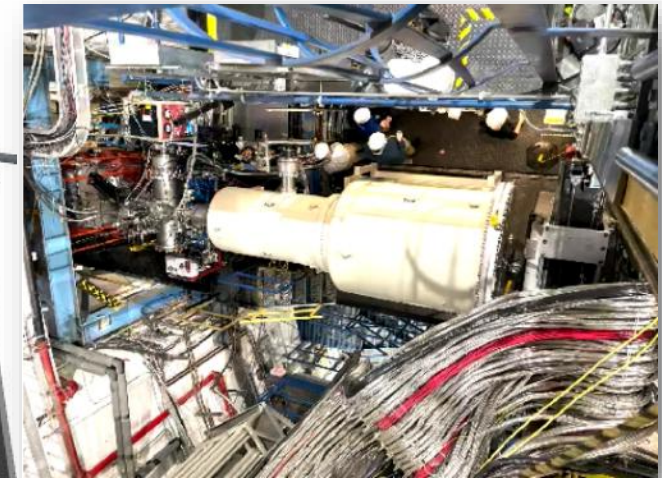
- Thin foil target ($1\ \mu\text{m}$ Ta)
- Large vacuum tanks to minimize scattering
- Two planes of GEM detectors for tracking
- HyCal calorimeter for electron/positron detection



GEM
Detectors



HyCal



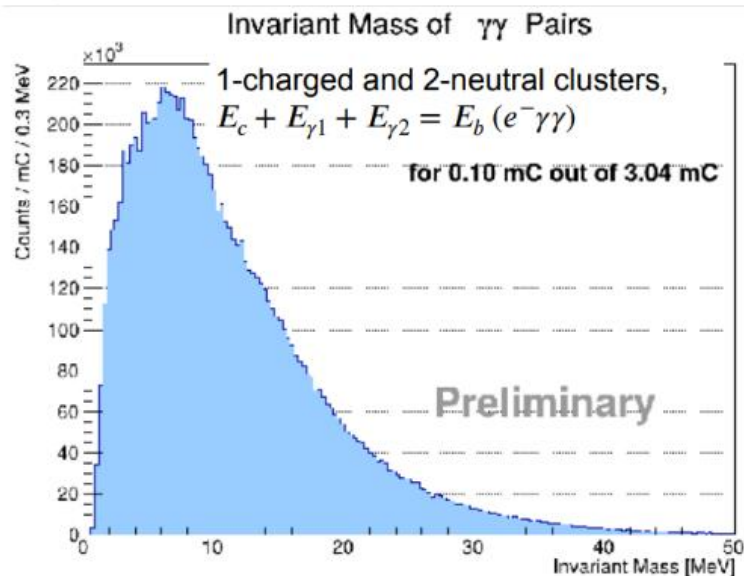
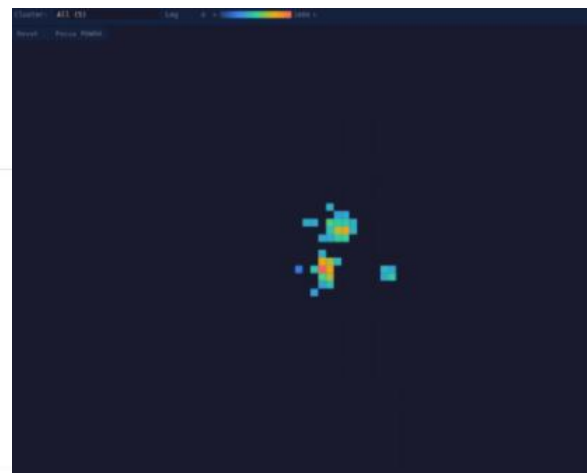
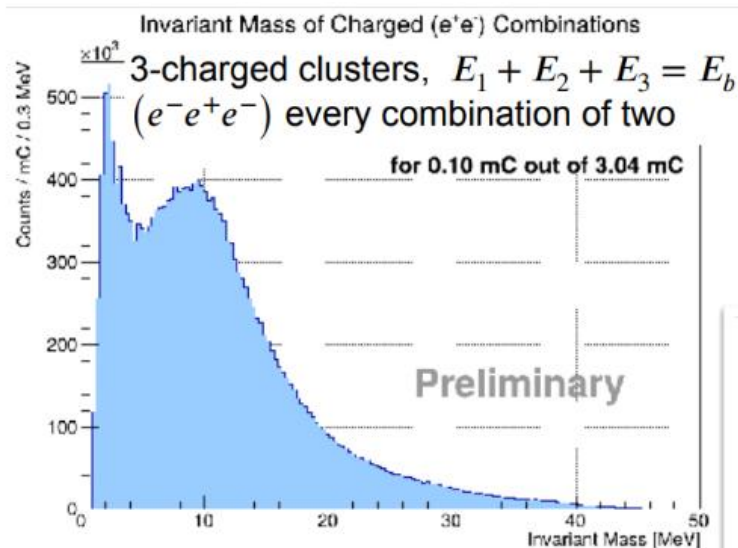
Top View

Status and Projected Sensitivity of X17 Search

Online spectra from Spring 2026 run

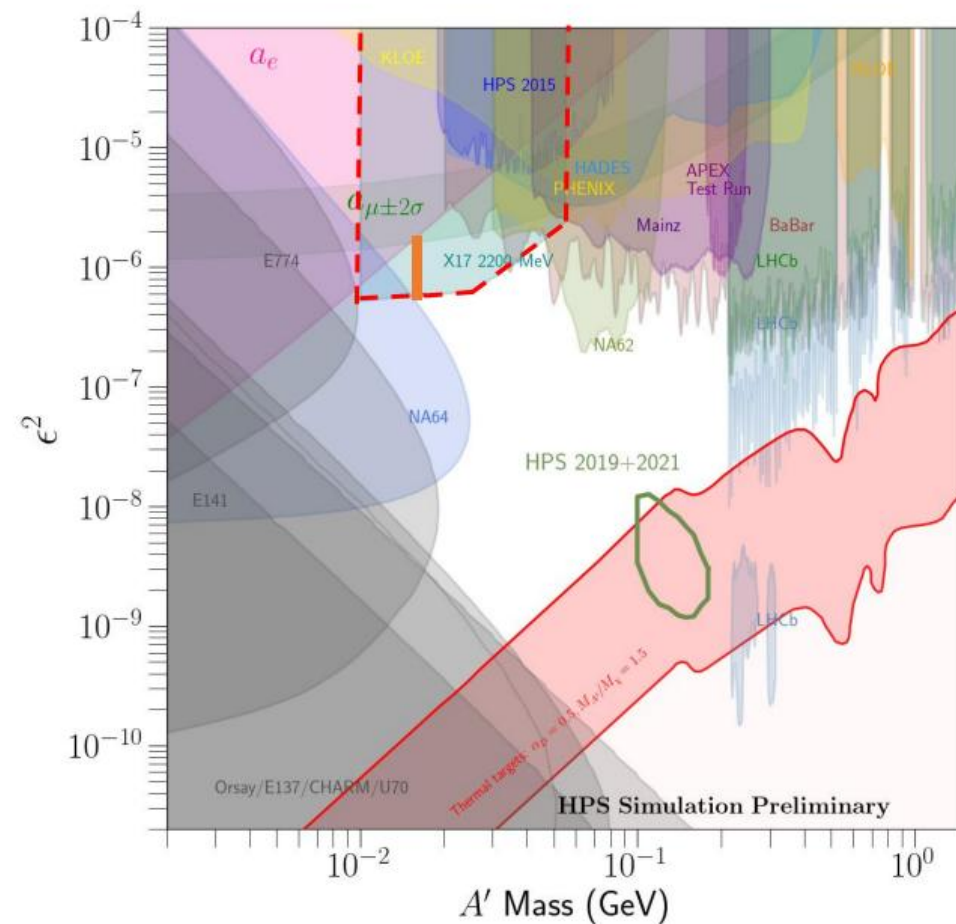
3-cluster event:

3-particle mass spectra:



Reach simulation

$E_{beam} = 2.2$ GeV, $I_{beam} = 50$ nA, 40 PAC days

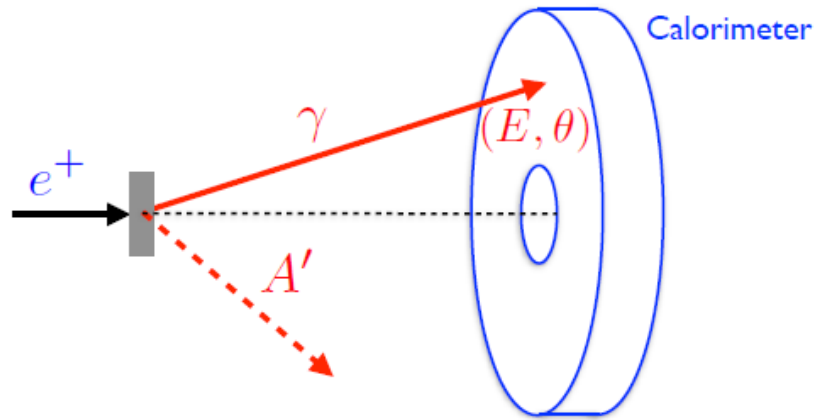


[PRad Collab. Meeting (2026), wiki.jlab.org/pcrowiki/index.php/Prad-II/X17_Mini_Collaboration_Meeting]

A' Search with Positrons

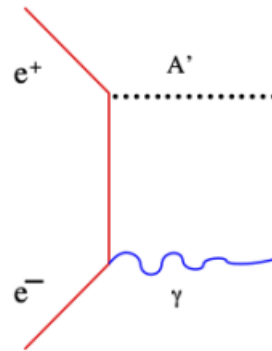
Proposal for positron annihilation experiment at Ce+BAF

$$e^+e^- \rightarrow \gamma + X$$

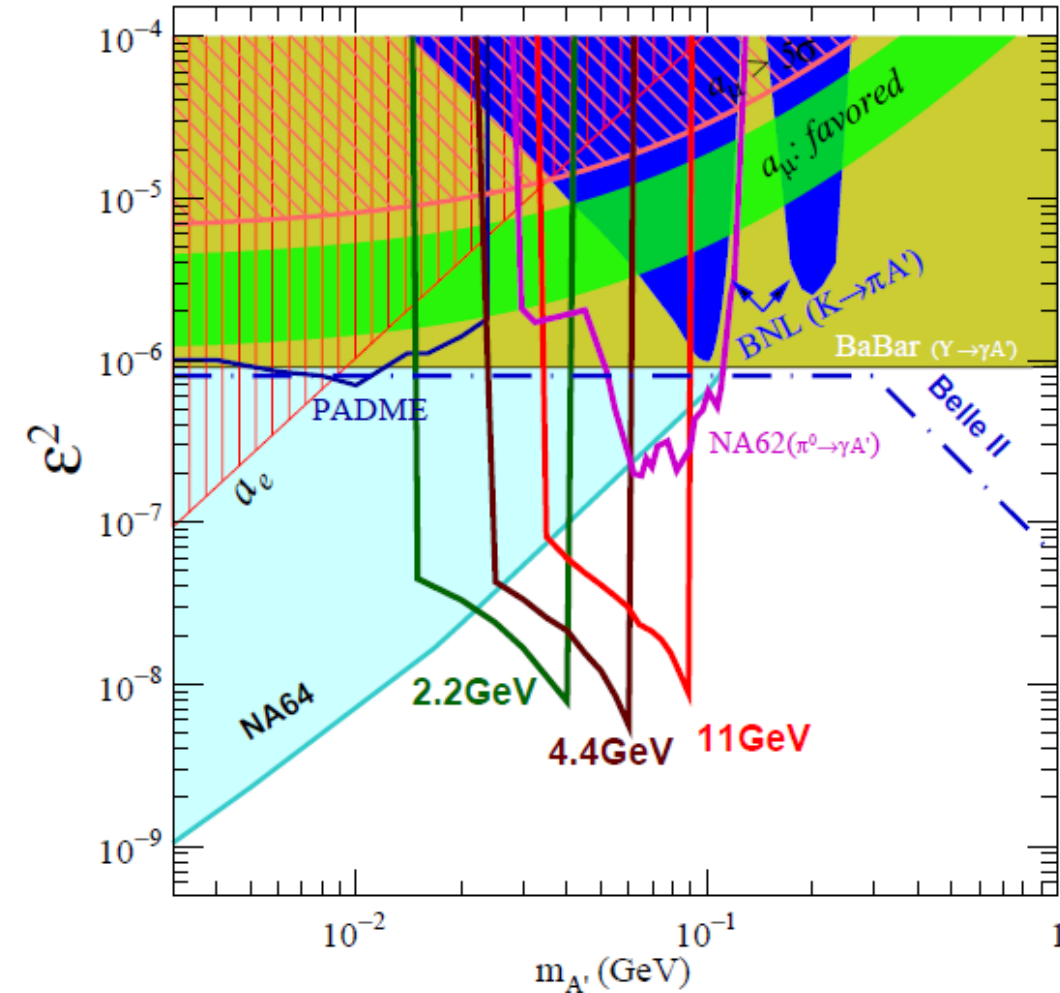


$$M_{\text{rec}}^2 = 2m_e \left(E_+ - E_\gamma \left(1 + \frac{E_+}{2m_e} \theta_\gamma^2 \right) \right)$$

- **Missing-mass search** from 15 – 90 MeV/ c^2
- Sensitivity reaches $\epsilon \geq 10^{-4}$

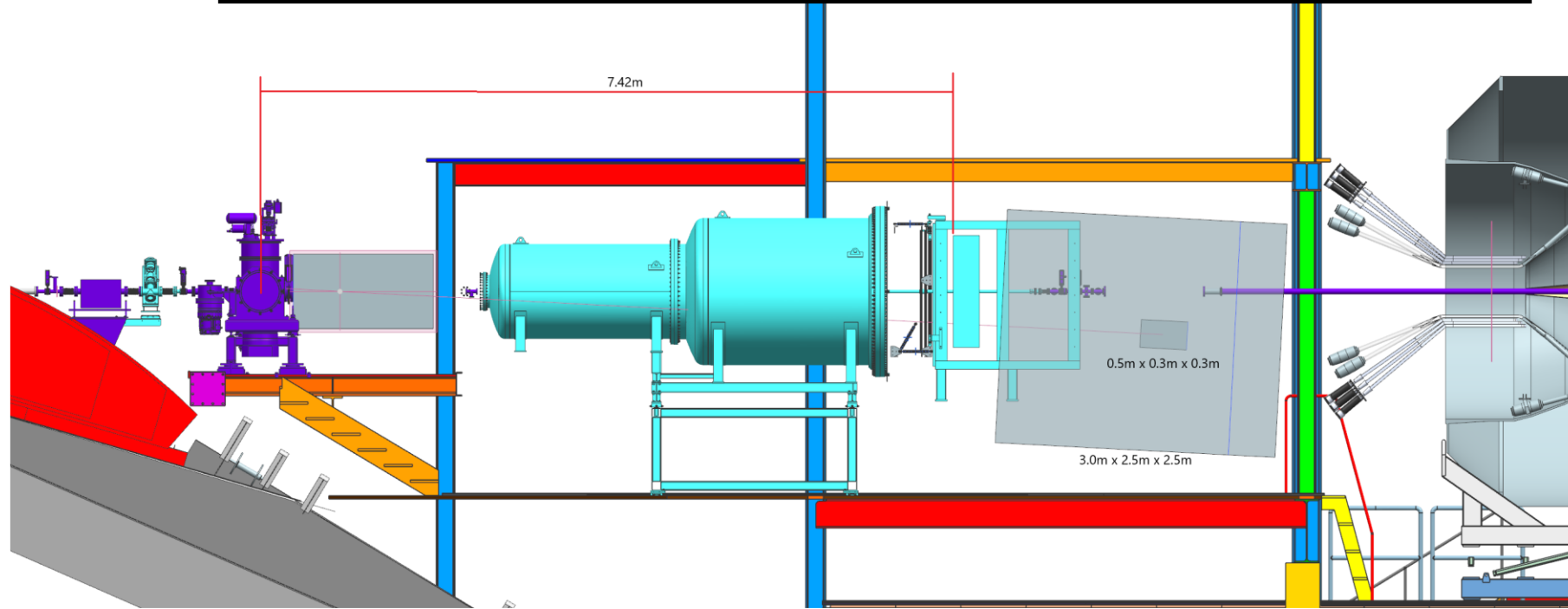


Reach simulation



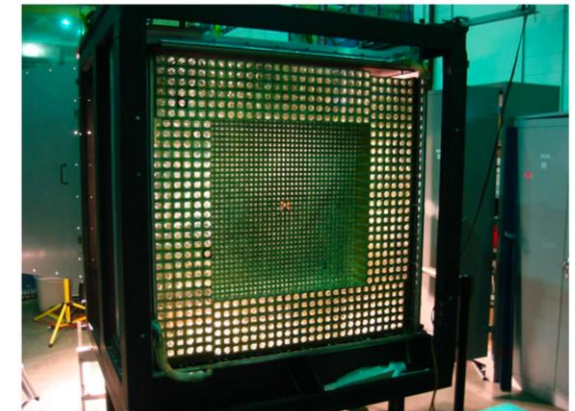
[B. Wojtsekhowski et al., accepted proposal PR12+24-005 at PAC52 (2024), www.jlab.org/exp_prog/proposals/24/PR12%2B24-005.pdf]

Setup for A' Search with Positrons in Hall B



Conditionally approved for Ce+BAF

- 50 nA positron beam, energies of 2.2, 4.4, and 11 GeV
- 5-cm-long target of liquid hydrogen
- Detection of photon from $e^+ + e^- \rightarrow A' + \gamma$ with HyCal
- Setup includes sweeper magnet and beam dump

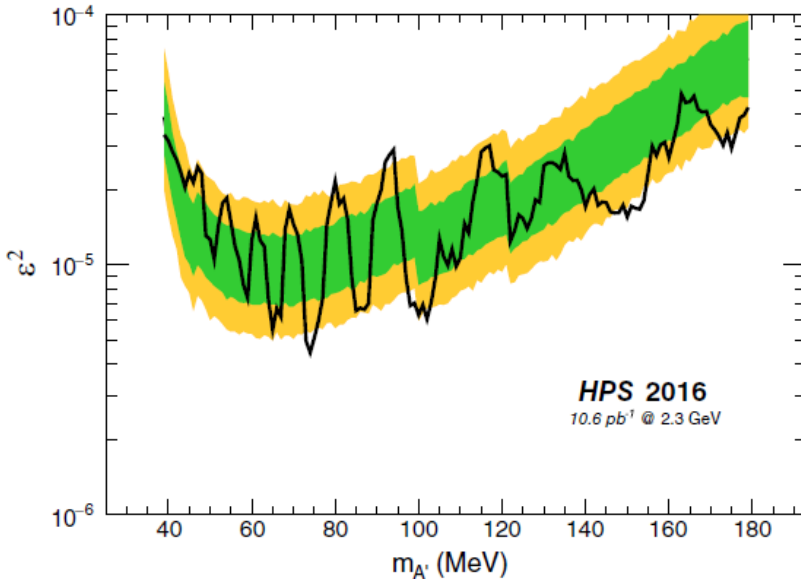


Heavy Photon Search (HPS) Experiment

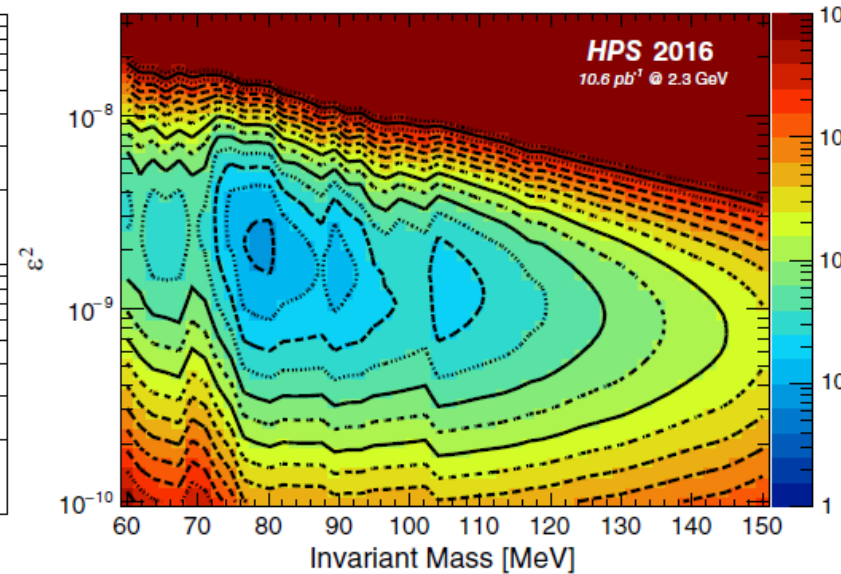
Canonical minimum A' Scenario

- Engineering run 2016: ~ 5 PAC days at 2.3 GeV (most analyzed dataset)

Bump hunt



Displaced vertex search



[HPS Collab., Phys. Rev. D 108, 012015 (2023)]

Existing data: Two physics runs completed

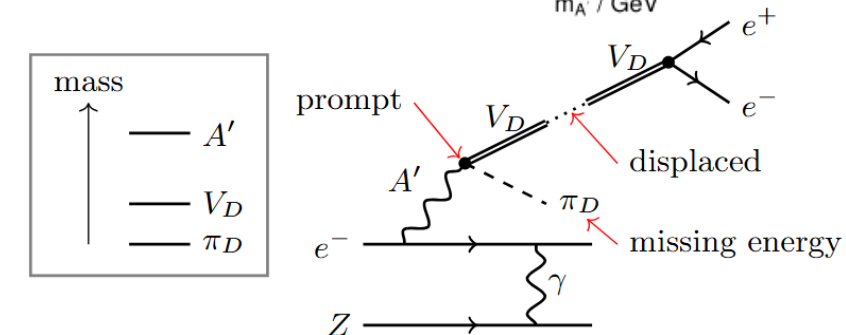
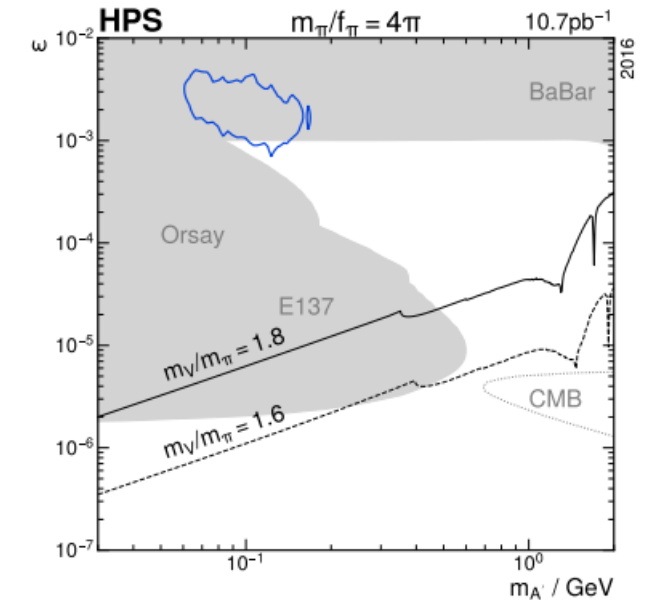
- Run 2019: ~ 14 PAC days at 4.55 GeV
- Run 2021: ~ 24 PAC day at 3.74 GeV

Future runs: ~ 100 more PAC days

SIMP Scenario

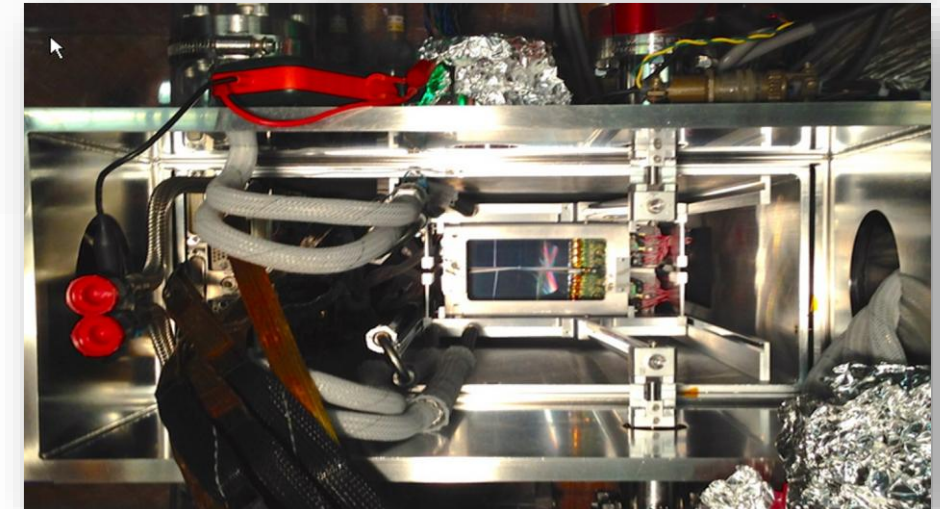
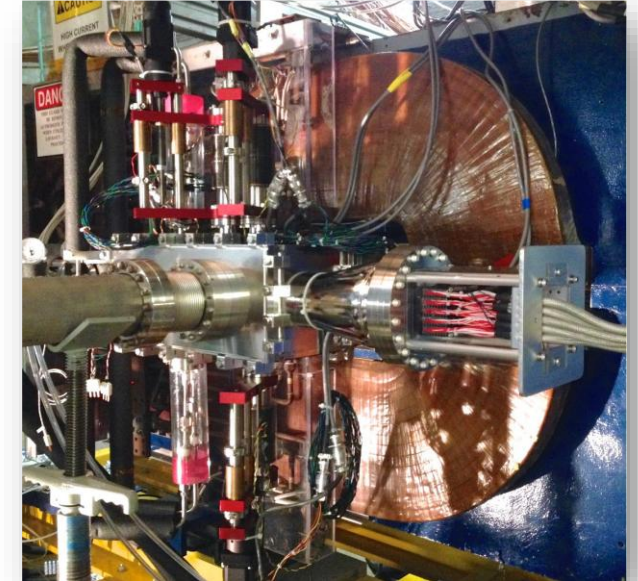
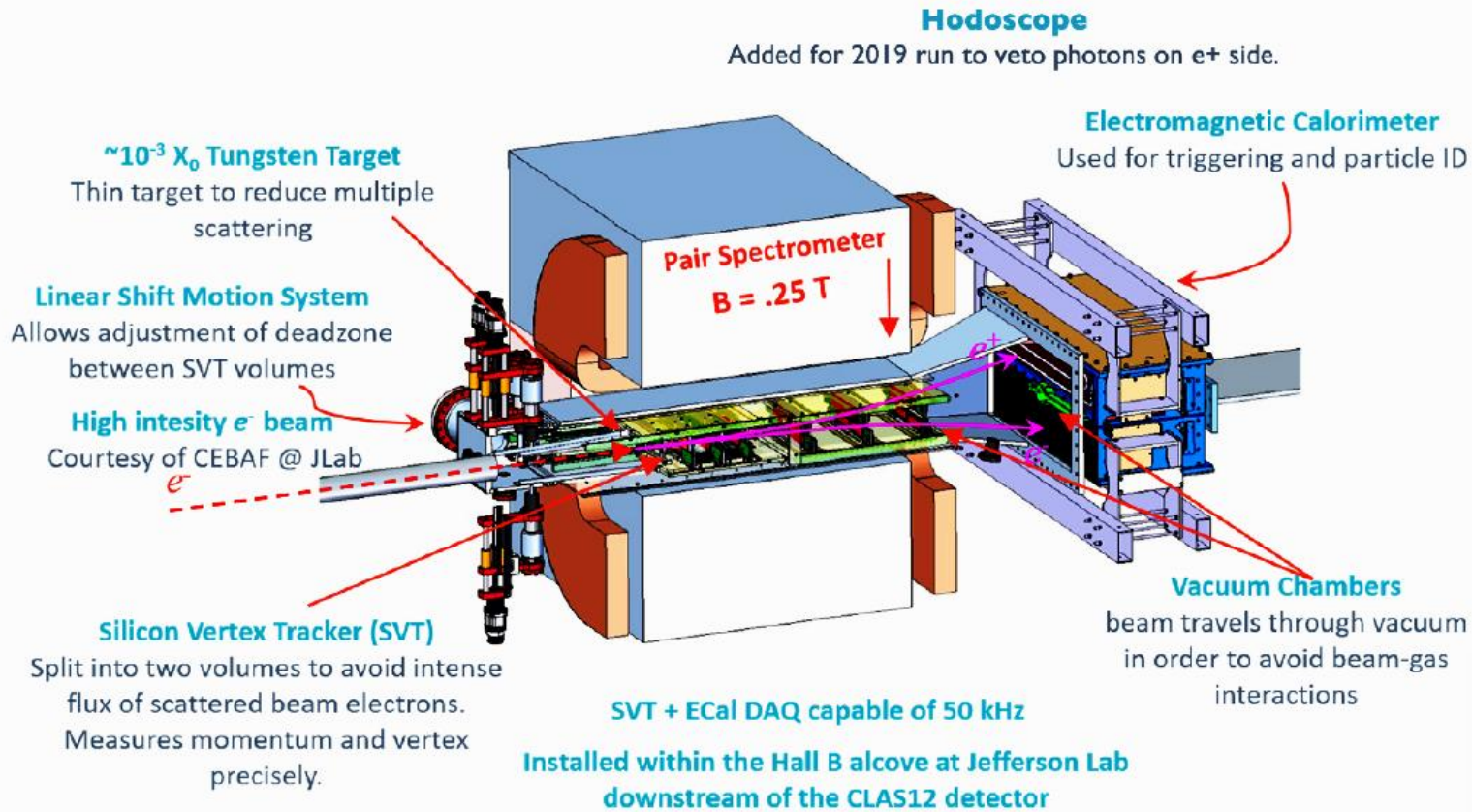
- Assuming dark pions and dark ρ mesons

Displaced vertex search



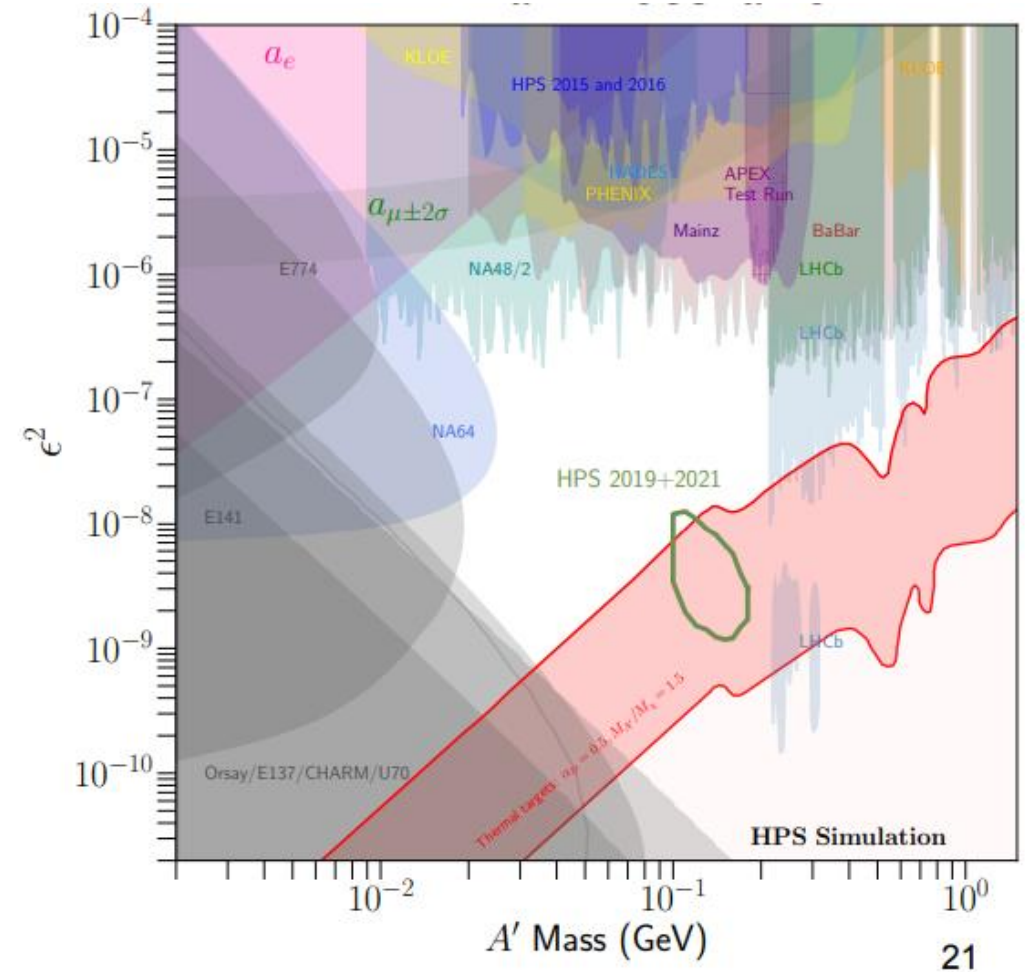
[HPS Collab., Phys. Rev. D 113, 032019 (2026)]

Setup for HPS in Hall B Alcove



Status and Projected Sensitivity of HPS

Reach simulation



[T. Nelson, "HPS Overview", HPS Collaboration Meeting (June 2025), indico.jlab.org/event/965/]

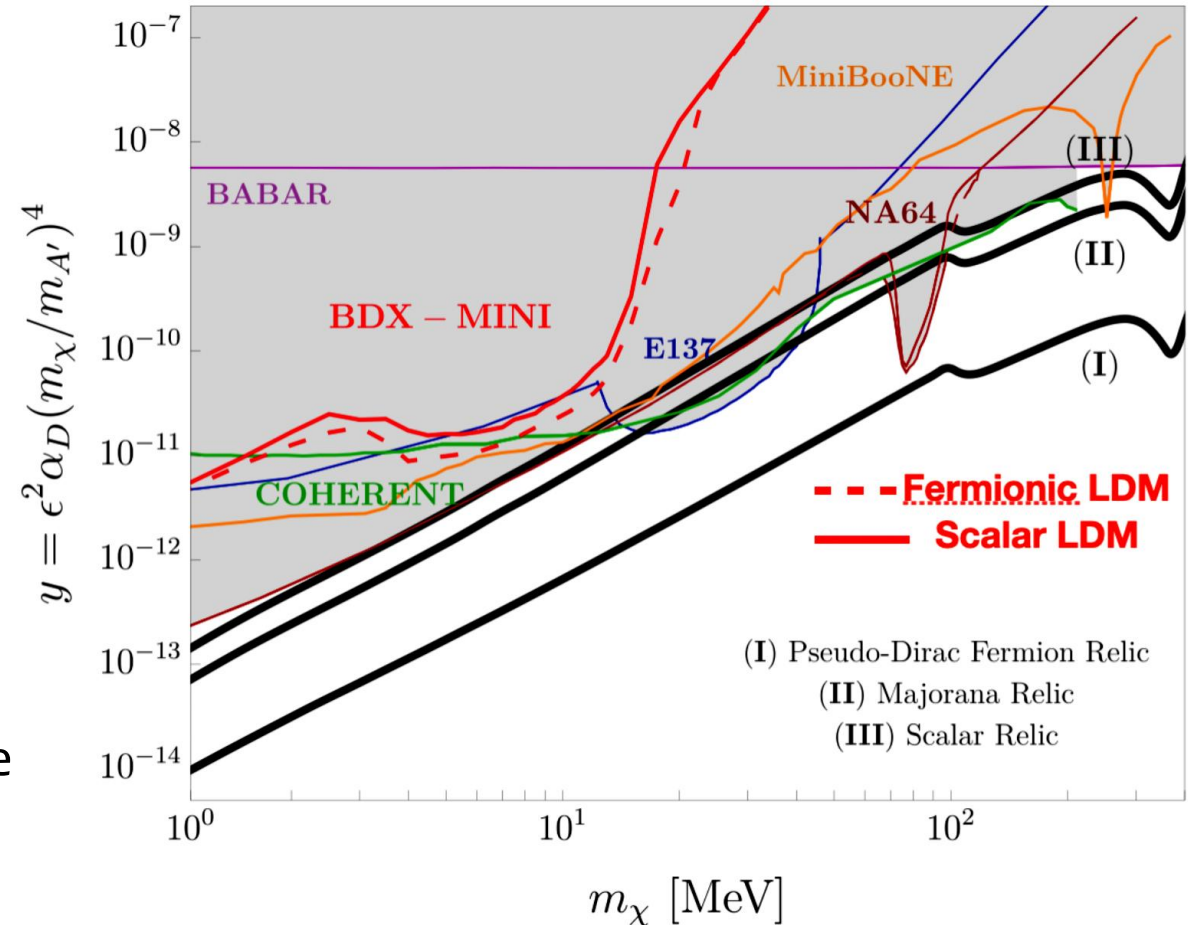
BDX-MINI Experiment

- **Small-scale** version of a **beamdump** experiment
- Detectors ~ 25 m behind dump in wells
- Shielded by concrete and soil
- Approx. 50 PWO crystals

Existing data

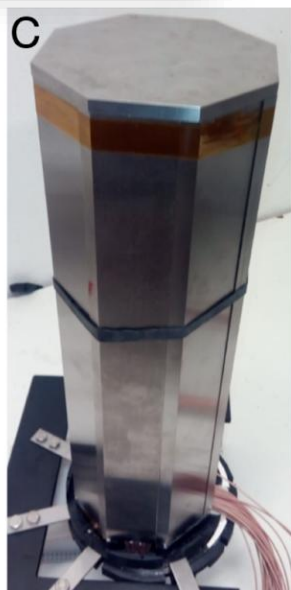
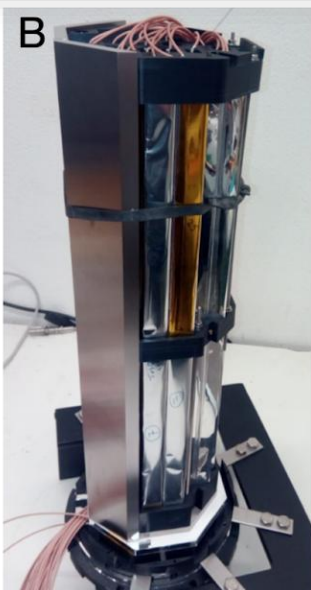
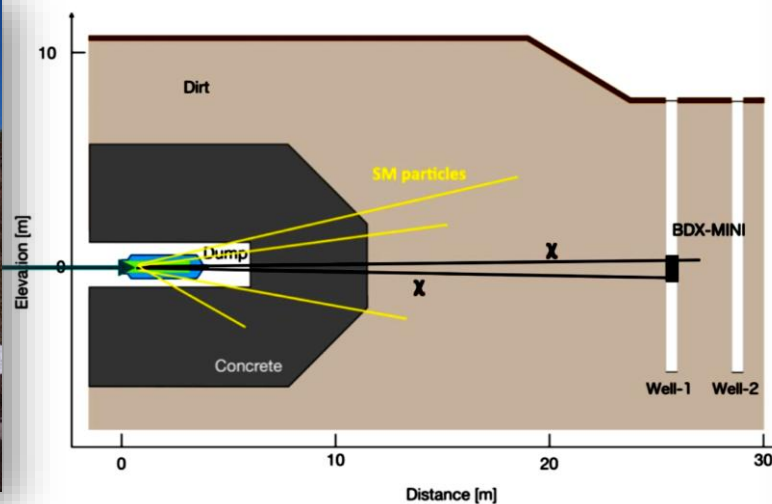
- Data-taking in **2019 – 20** completed
- Integrated charge: 2.6×10^{21} EOT
- 2.2-GeV, 150- μ A electron beam
- Some controlled background
- Sensitive to parameter space only covered by some of most- sensitive experiments to date
- **BDX-MINI demonstrated capability and readiness**

Exclusion limits



[M. Battaglieri et al. Phys. Rev. D 106, 072011 (2022)]

Setup for BDX-MINI Behind Hall A Beamdump

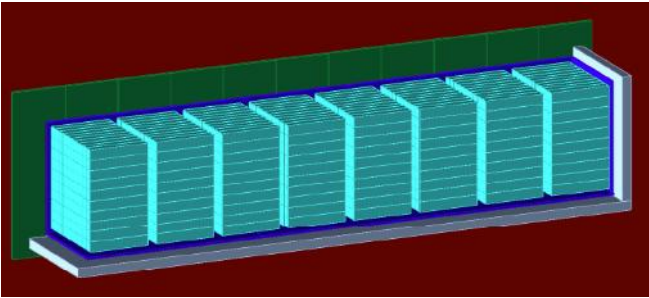


[M. Battaglieri et al., Eur. Phys. J. C 81, 164 (2021)]

Status and Projected Sensitivity of BDX Experiment

Electromagnetic Calorimeter

- Sensitive down to ~ 100 MeV electromagnetic showers
- Homogeneous 4 tons



Crystals

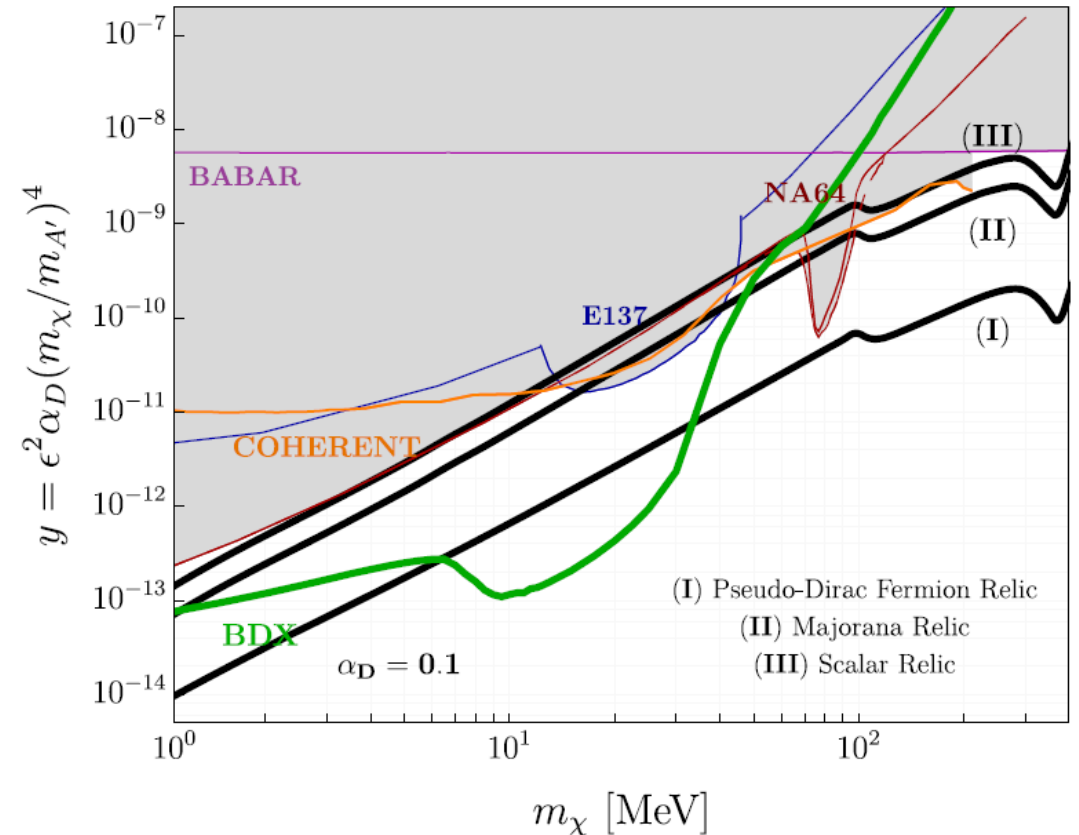
- **BGO** (from BGO-OD experiment, Bonn)



Active veto: 2-cm thick plastic scintillator

Reach Simulation

- 11 GeV, 65 μ A
- 10^{22} EOT
- $E_{\text{tot}} > 300$ MeV



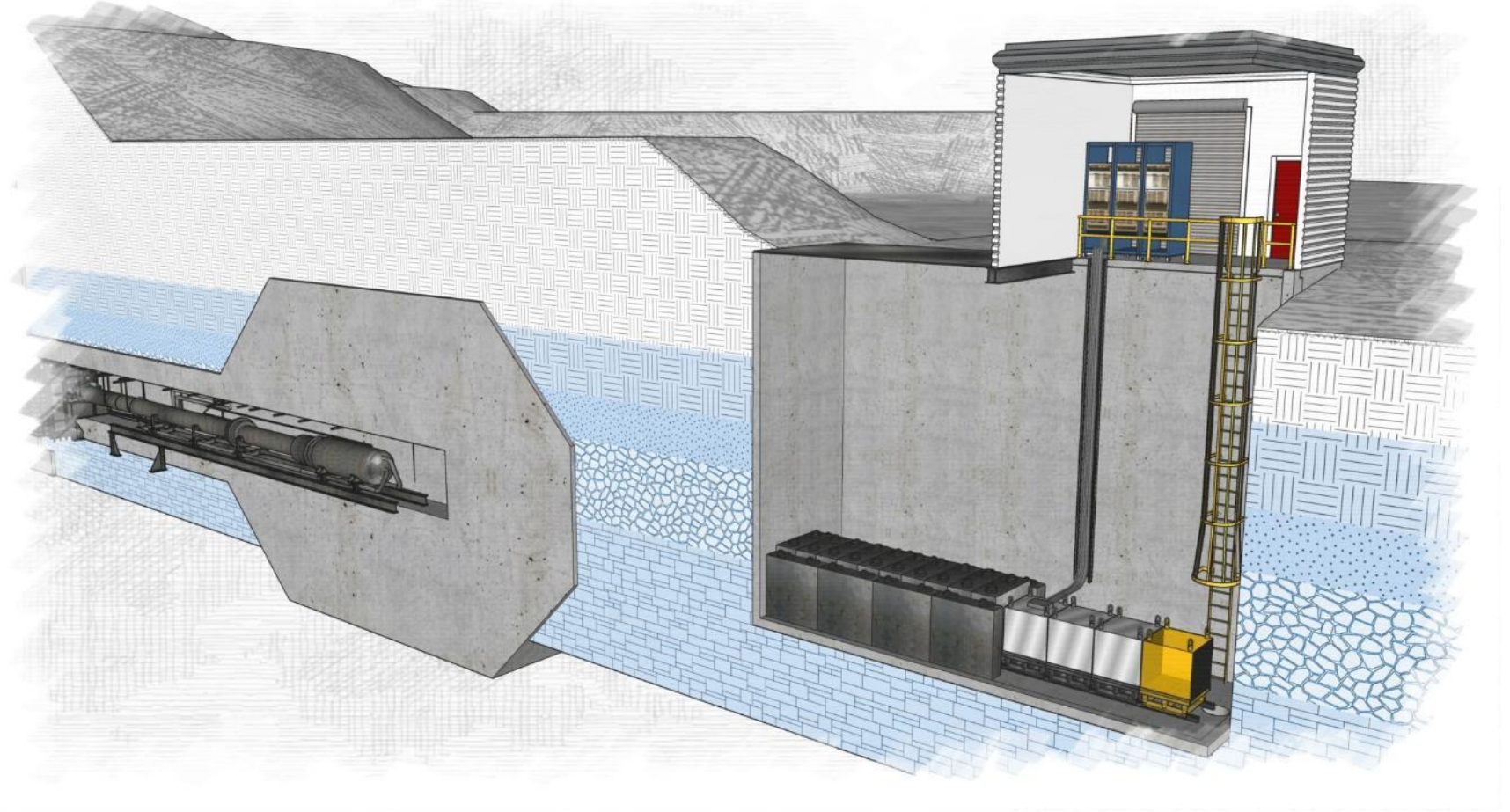
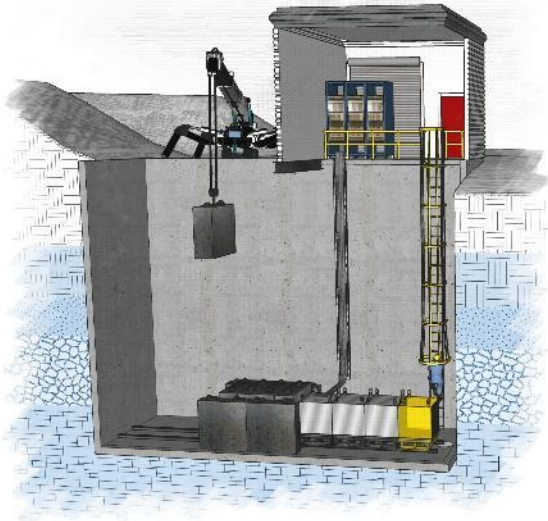
BDX could improve exclusion limits in parameter space by 2 orders of magnitude

[M. Battaglieri et al., accepted proposal PR12-16-001 at PAC46 (2018), www.jlab.org/exp_prog/proposals/18/C12-16-001.pdf]

Setup for BDX Behind Hall A Beamdump

Design

- Detector inside vault
~20 m behind dump
- 5.5 m concrete + 8 m dirt
+ 5.5 m steel shielding
- No sizable overburden
- Installation from
overground:



Summary of Dark Sector Searches at Jefferson Lab

Past:

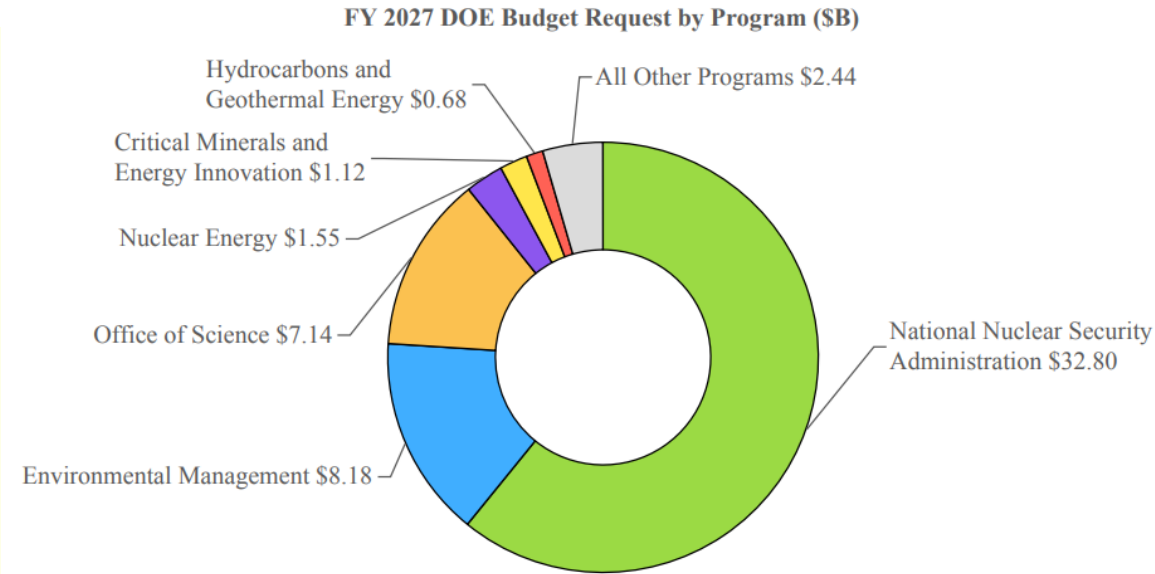
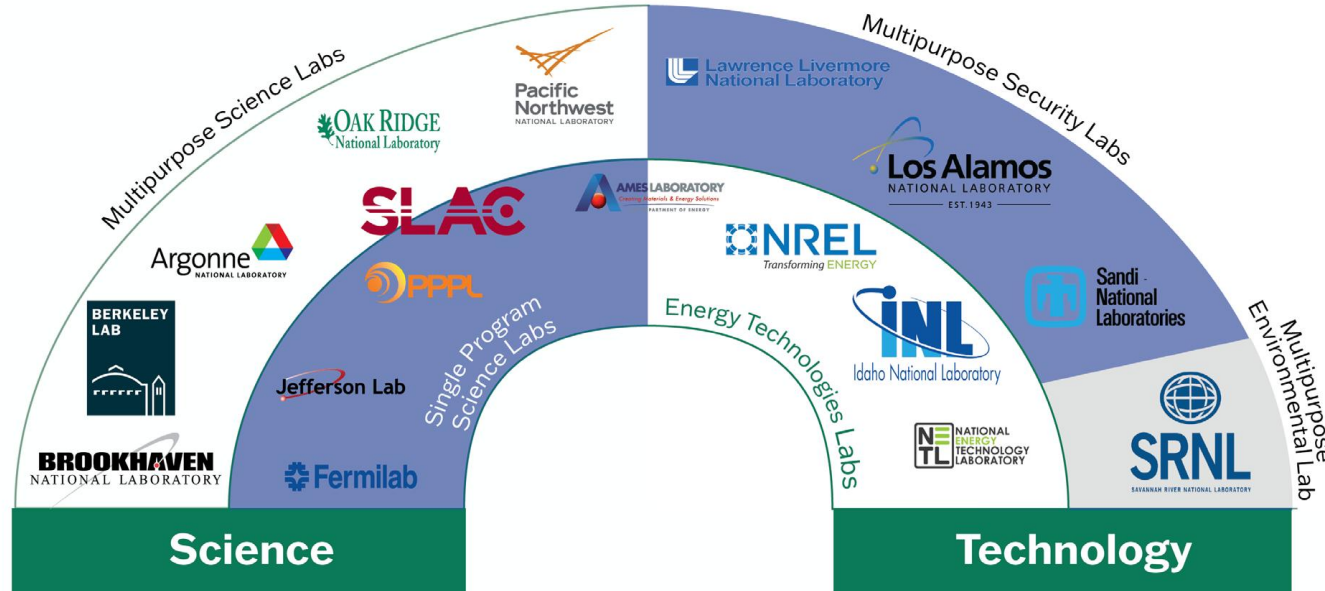
- **APEX** (Hall A) took data in 2019 that is being analyzed (**first results published in 2011**)
- **HPS** (Hall B) pioneered displaced vertex & SIMP searches (**first results published in 2023 & 2026**)
*Collected ~ ½ data set 2015 – 2021 and is **possibly continuing in 2029***
- **BDX-MINI** pioneered beamdump searches (**results published in 2022**)
- **PRad-X17** (Hall B) is most recent dark sector search experiment at Jefferson Lab
*Collected ~ ½ data set 2026 and is **scheduled to continue in Spring 2027***

Future:

- **BDX** has been proposed as full beam dump experiment (**requires new secondary beam facility**)
- **A' Search** (Hall B) has been proposed for Ce+BAF (**requires positron upgrade of CEBAF**)

Jefferson Lab as a DOE National Laboratory

Jefferson Lab is a Federally Funded Research and Development Center managed and operated (M&O) under contract with the **Department of Energy (DOE)**



Total = \$53.91 Billion

Jefferson Lab used to be a **program-dedicated, single-purpose DOE science laboratory**

DOE: “UNLEASHING THE GOLDEN ERA OF AMERICAN ENERGY DOMINANCE, ACCELERATING SCIENTIFIC CAPABILITIES, AND PROTECTING THE NATION”

[Department of Energy, Budget in Brief FY 2027 Congressional Justification (2026), <https://www.energy.gov/documents/doe-fy-2027-budget-brief>]

Jefferson Lab Funding Sources



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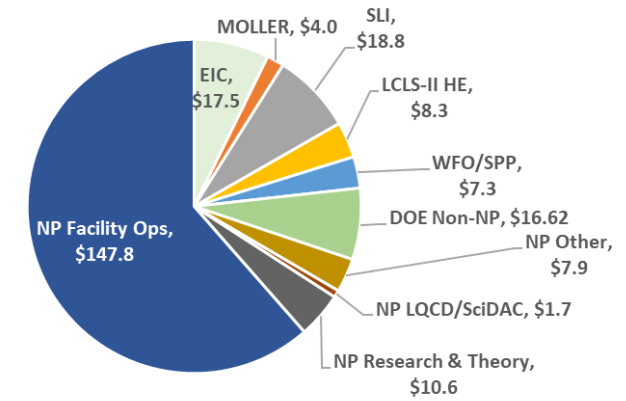
Office of Laboratory Policy
(OLP)
Nicholas Dienna (A)

Consolidated Service Center
(CSC)
Geoffrey deBeauchair

Office of Corporate
Business Operations
(OCBO)
Howard Dickenson

Jefferson Lab funding was 99% DOE
of which ~ 80% was **Nuclear Physics (NP)**

FY 23 LAB FUNDING BY FUNDING SOURCE
\$240.5M TOTAL



Facility operation >> Research funds

09/06/2026

<https://science.osti.gov/About/Organization>

Nuclear Physics Budget in Brief

Jefferson Lab =
Medium Energy

(dollars in thousands)

Nuclear Physics

	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Enacted	FY 2026 Enacted	FY 2027 Request	FY 2027 Request vs FY 2026 Enacted
Medium Energy, Research	59,083	50,055	51,455	46,932	31,410	-15,522
Medium Energy, Operations	149,834	138,620	146,242	155,000	156,613	+1,613
Total, Medium Energy Physics	208,917	188,675	197,697	201,932	188,023	-13,909
Heavy Ion, Research	46,149	45,474	47,454	46,312	33,662	-12,650
Heavy Ion, Operations	182,087	166,993	187,000	182,805	140,000	-42,805
Heavy Ion, Projects	20,000	2,850	2,850	2,850	—	-2,850
Total, Heavy Ion Physics	248,236	215,317	237,304	231,967	173,662	-58,305
Low Energy, Research	77,651	75,159	76,967	61,592	45,755	-15,837
Low Energy, Operations	128,579	120,401	134,646	143,597	147,005	+3,408
Low Energy, Projects	23,940	9,259	5,259	17,000	—	-17,000
Total, Low Energy Physics	230,170	204,819	216,872	222,189	192,760	-29,429
Theory, Research	67,873	67,392	63,727	55,053	36,989	-18,064
Total, Nuclear Theory	67,873	67,392	63,727	55,053	36,989	-18,064
Subtotal, Nuclear Physics	755,196	676,203	715,600	711,141	591,434	-119,707
Construction						
20-SC-52 Electron Ion Collider (EIC), E	50,000	95,000	110,000	155,000	200,000	+45,000
Subtotal, Construction	50,000	95,000	110,000	155,000	200,000	+45,000
Total, Nuclear Physics	805,196	771,203	825,600	866,141	791,434	-74,707

FY23 to 27: JLab Research -47%, JLab Total -10%

[Department of Energy, *Budget in Brief*, FY 2027 Congressional Justification (2026), www.energy.gov/documents/doe-fy-2027-budget-brief]

The Vision as Presented by the Director

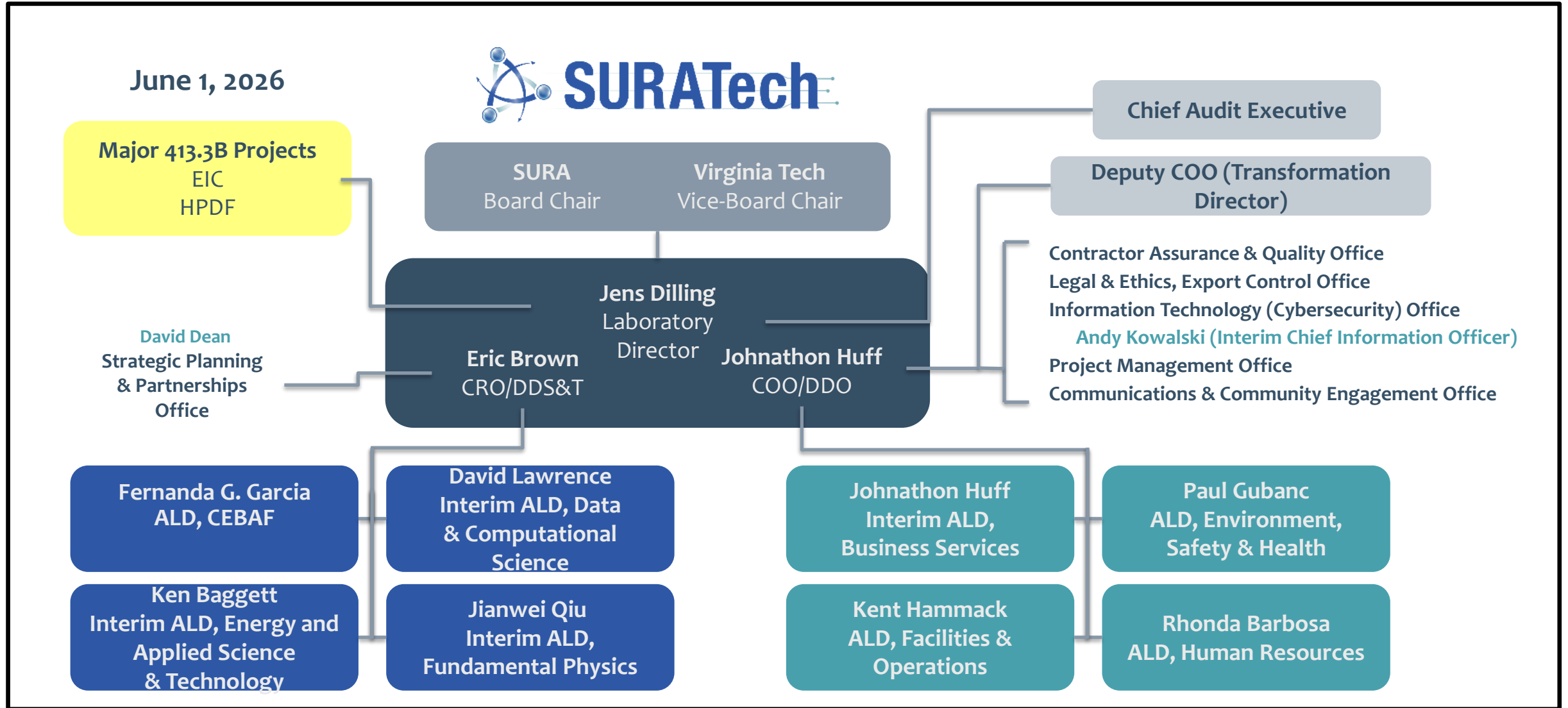
*Deliver a thriving **multi-program laboratory** with world-leading scientific capabilities and User Facilities driven by safety and excellence in Laboratory Operations that enables discoveries in **three science pillars** aligned with the lab's core capabilities and national priorities:*

- 1. Nuclear Physics*
- 2. Data and Computational Science*
- 3. Energy and Applied Sciences*

[\[J. Dilling, PAC 53 Meeting \(2025\), \[indico.jlab.org/event/923/\]\(https://indico.jlab.org/event/923/\)\]](https://indico.jlab.org/event/923/)

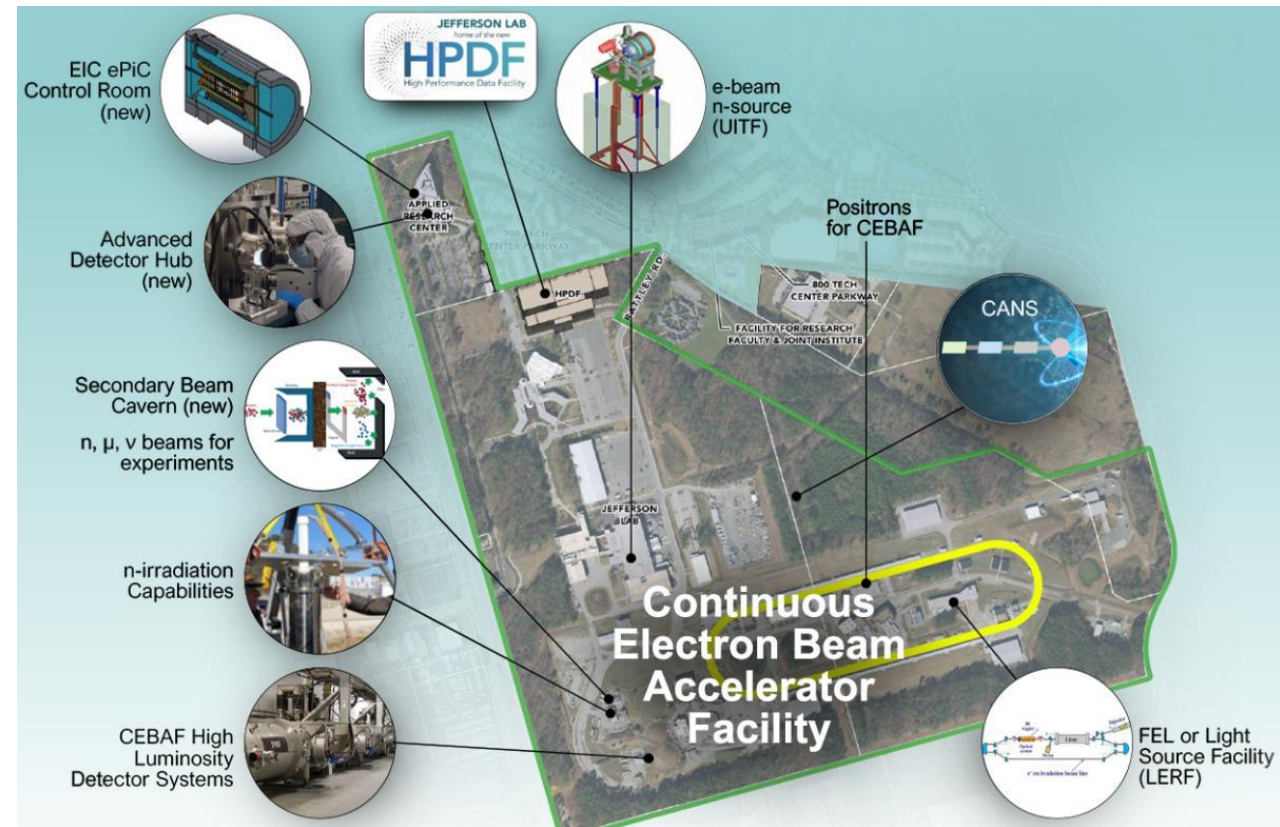
Remember: Dark Matter is part of DOE's High Energy Physics program

The Structure as Presented by the Director



[J. Dilling, PAC 54 Meeting (2026), indico.jlab.org/event/1080/]

10/20-Year Outlook as Presented by the Director



- Continuation of **CEBAF Nuclear Physics Program**
- Growing to a **multi-program laboratory**
- Future expansions proposed over the next 20 years supported by:
 - › working with the scientific **user community** for buy in on priorities
 - › Planning community-oriented strategy planning exercises, for CEBAF and other sectors
 - › CEBAF 2037 and beyond
 - › Beam Dump opportunities in fundamental and applied sciences
 - › FEL, n-sources...

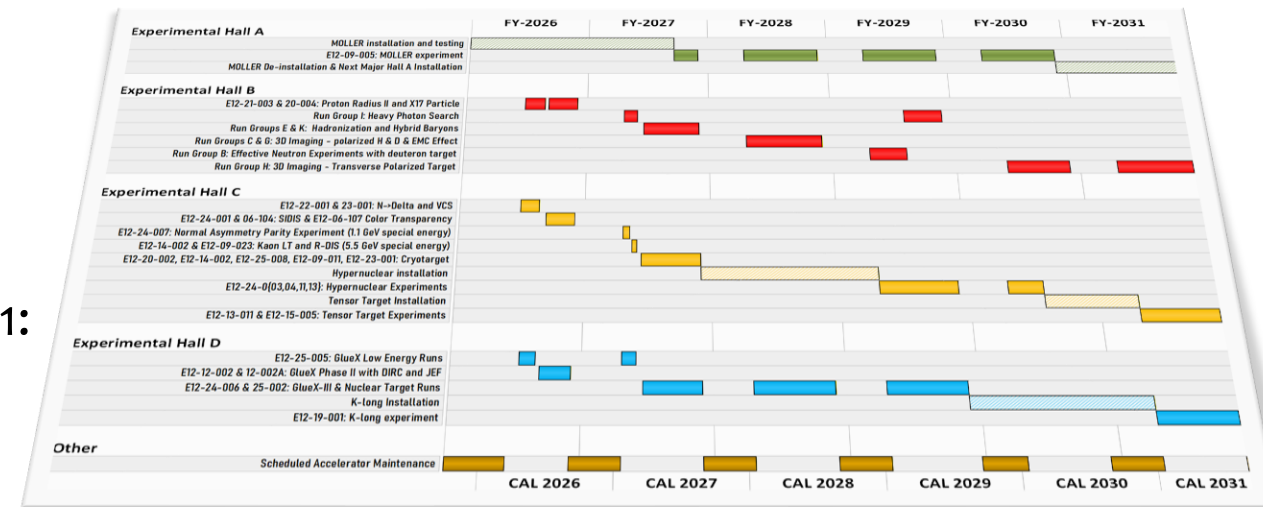
[J. Dilling, PAC 54 Meeting (2026), indico.jlab.org/event/1080/]

5-Year CEBAF Program as Presented by the AD

- **Hall A** will run MOLLER Experiment and then start transition to next large-scale experiment
- **Hall B** will complete high impact run group experiments and then start transversely polarized target SIDIS program around end of decade
- **Hall C** will install and run hypernuclear experiments and then start tensor polarized deuteron experiments
- **Hall D** will run GlueX-III & 2nd gen. real photon experiments and then install & run K-Long experiment

[D. Higinbotham, PAC 53 Meeting (2026),
indico.jlab.org/event/1080/]

Detailed run schedule
available up to year 2031:



Recent Developments at Jefferson Lab and DOE

- Jefferson Science Associates (a SURA company) has managed the lab since 2006; In 2025, the M&O contract went to a recompetete bidding competition
- Stuart Henderson was Director for more than seven years until Aug. 1, 2024; Kim Sawyer was serving as director until June 30, 2025; **Jens Dilling** serves since then
- The Associate Directors for *Physics* and for *Accelerator Operations, Research and Development* had to leave their positions on Nov. 21, 2025
- DOE awarded **SURATech** the M&O contract beginning June 1, 2026.
- In 2026 Office of Science underwent major organizational realignment: **merger of Office of Nuclear Physics (NP) and Office of High Energy Physics (HEP)** into a combined office; Previously, HEP and NP were separate offices, with distinct leadership, programs, and budgets; SC-1 is vacant

Comments on the Future of Jefferson Lab

- The proposed **22-GeV energy upgrade** to CEBAF would have doubled CEBAF's maximum energy, but is no longer pursued
- The proposed **next large-scale experiment** in Hall A was the large-acceptance spectrometer SoLID, but is no longer pursued in its original extend
- The proposed **secondary beam facility** was to be build upon the BDX design, but requested funds for the BDX engineering design have been declined
- CEBAF has a **full run schedule** for many years to come;
Hall B has 10 years of running accepted, not counting new run groups that will be added over the years
- Jefferson Lab is **transitioning into a multipurpose lab**
expanding the program into data science and energy and applied sciences
- A future search experiment could possibly be connected with new beamlines or experimental sites (such as the **secondary beam facility** or **positron injector**) relating to “**CEBAF 2037 and beyond**”
- A future search experiment could possibly **benefit from the program expansion** of Jefferson Lab and the merger of the NP and HEP offices at DOE avoiding program tensions of the past

(but not predicting Jefferson Lab's future)