

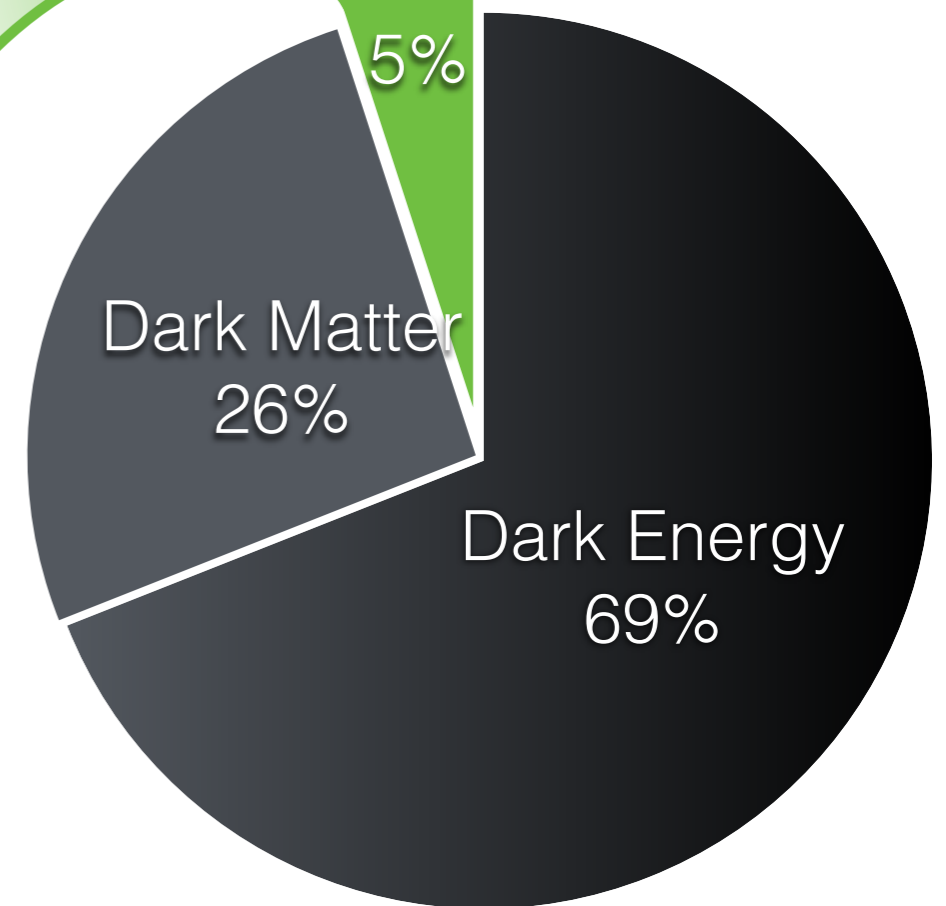
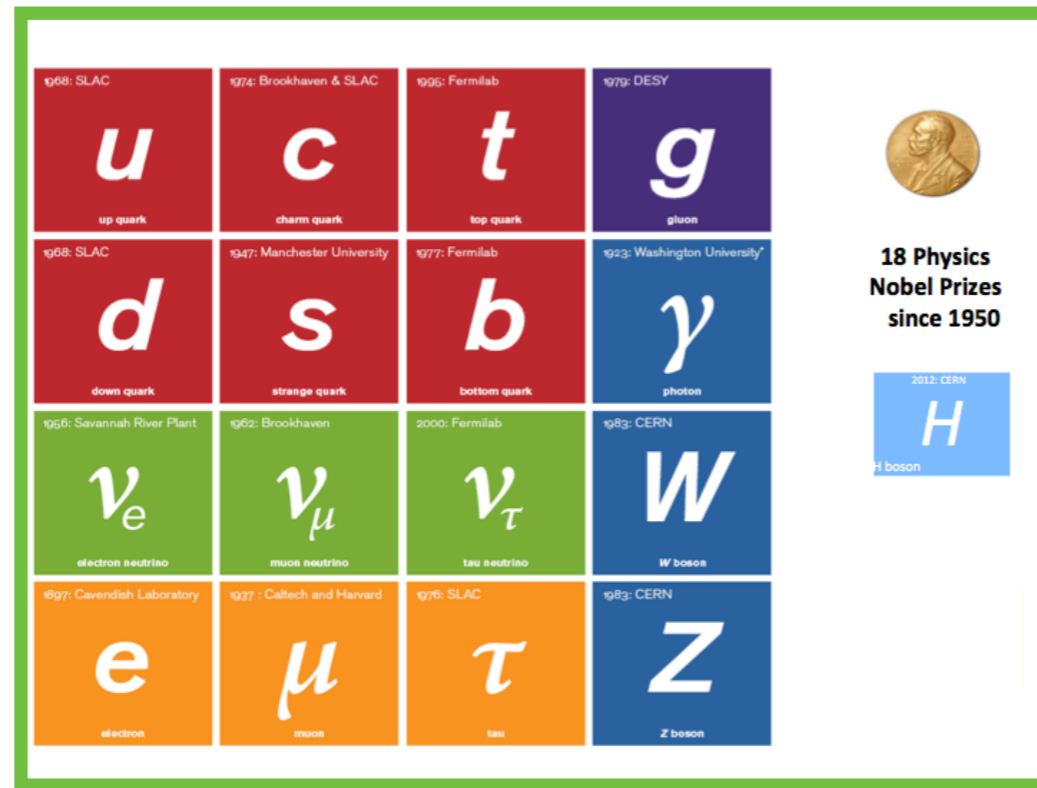
# DarkLight Annual Progress Report

Ross Corliss *on behalf of the collaboration*  
TRIUMF PP-EEC Review  
May 2024

# DarkLight at ARIEL

- Experiment approved in 2021 for 1000+300 h beam time
- Prototype target chamber and background studies in 2022
- Hosted ARIEL scientific opportunities workshop in 2022
  - Topical collection published in Journal of Science  
<https://iopscience.iop.org/issue/1742-6596/2391/1>
- Simulation, revision of magnet design, testing of detector components in 2023
- Meanwhile:
  - X17 anomalies continue to drive substantial interest
  - Many experiments now targeting X17 parameter space

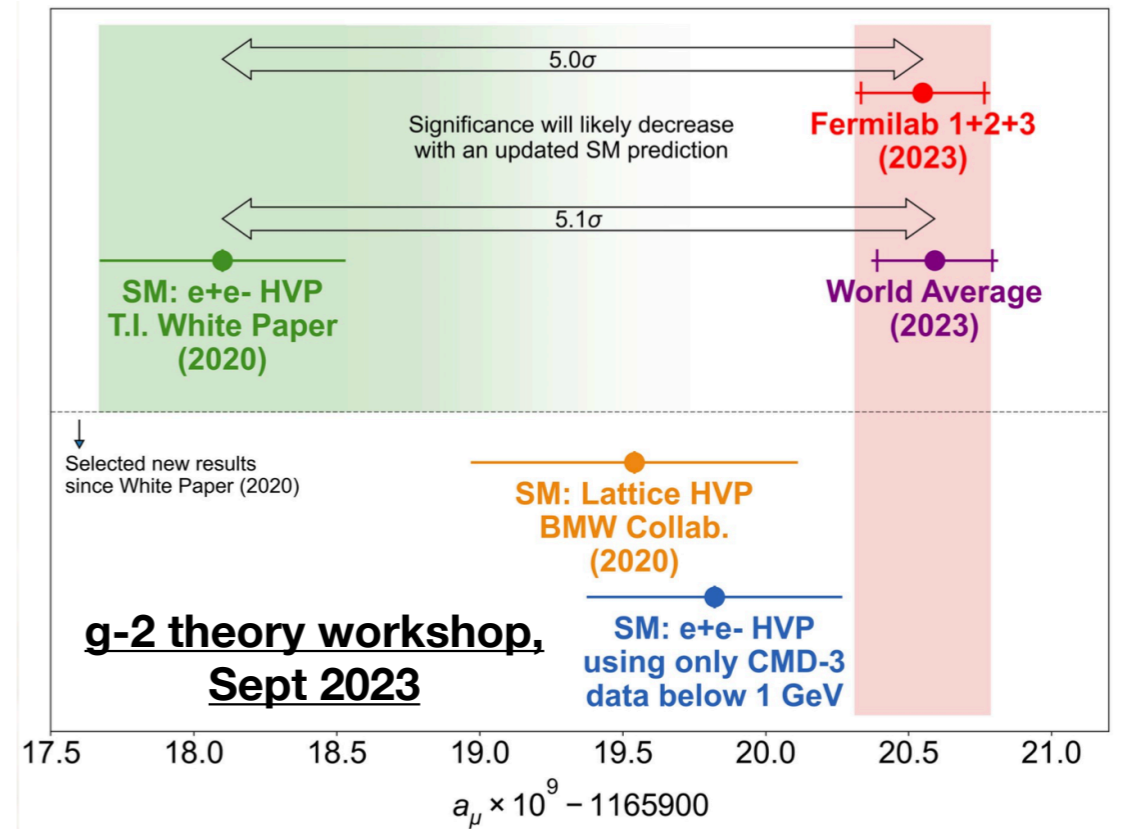
# Searching for BSM Physics



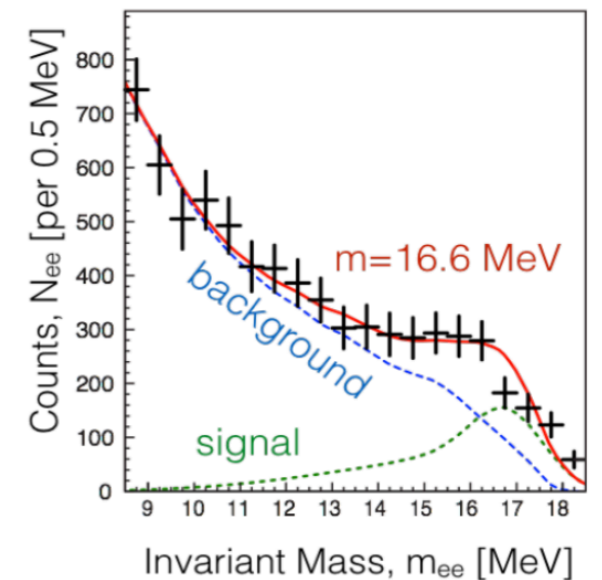
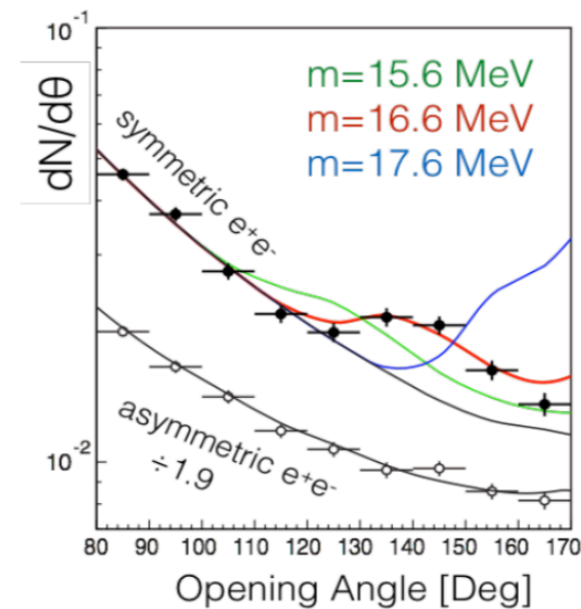
- Dark Matter: Massive + ???
- Dark Energy: ???
- Large parameter space even for simple models
- Need broad searches, or focus on anomalies

# Anomalies

- FNAL g-2 combined result (arxiv:2308.06230)

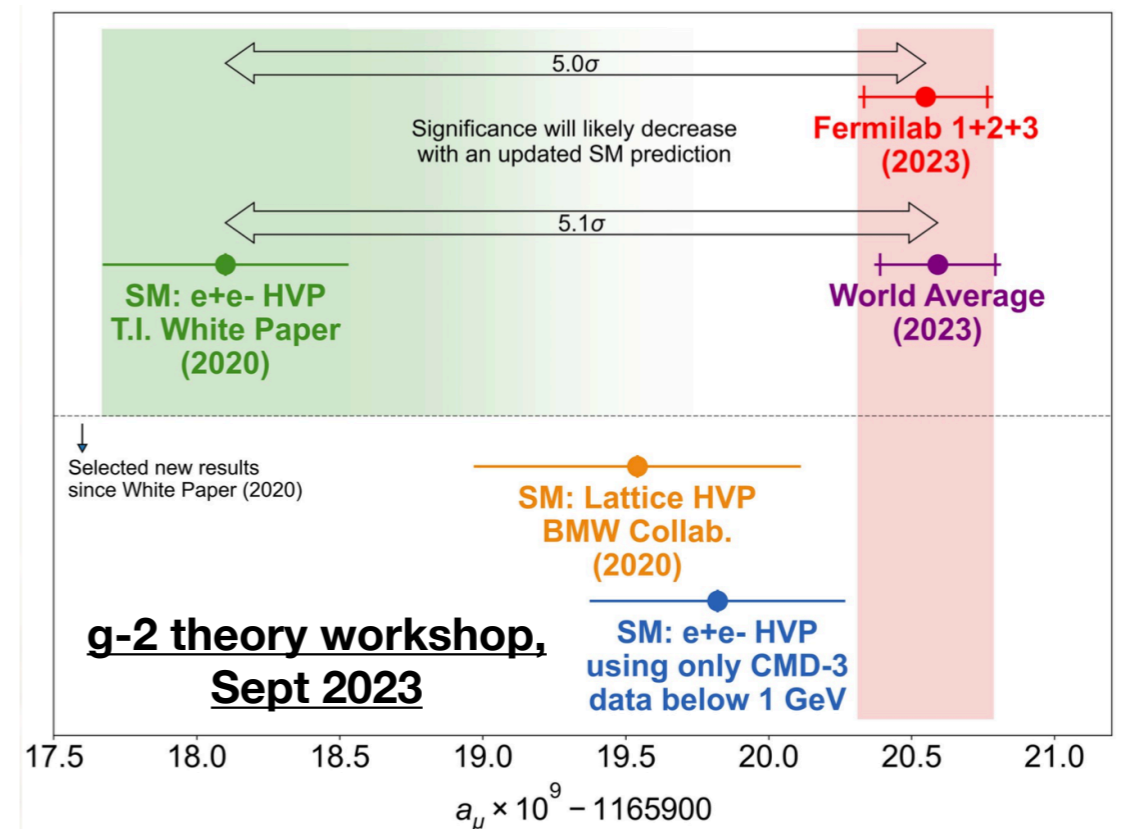
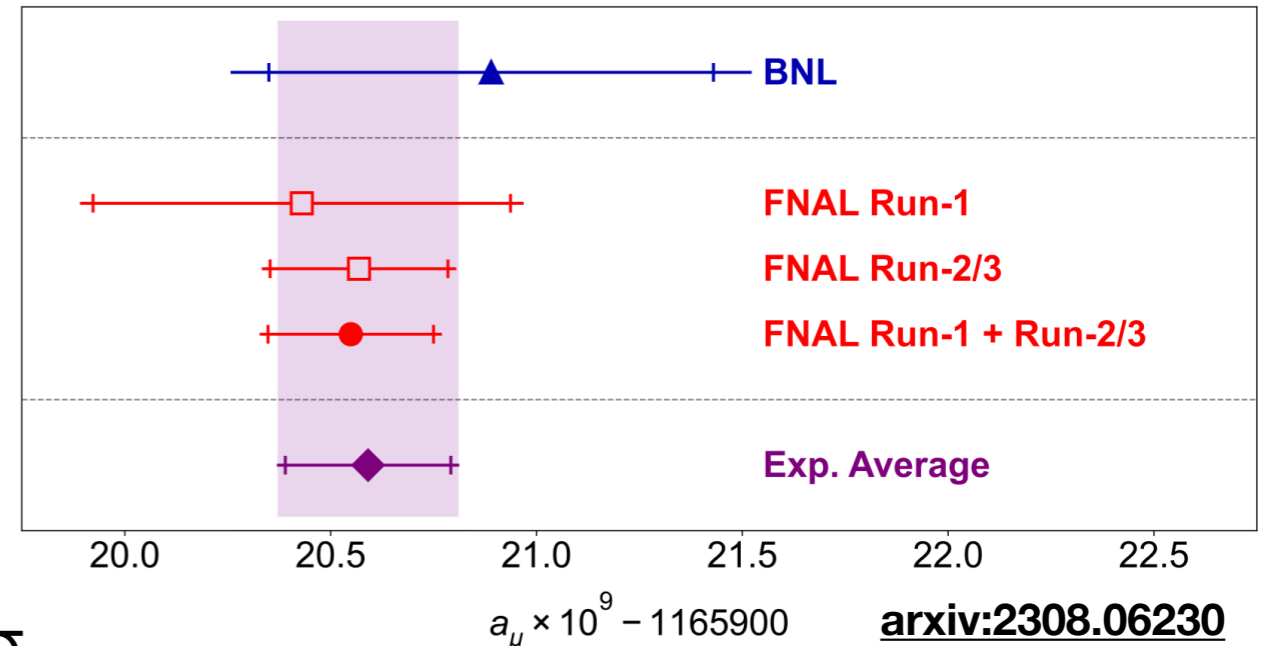


- ATOMKI X17 in  $^8\text{Be}$ 
  - and  $^4\text{He}$ ,  $^{12}\text{C}$  (arxiv:2209.10795),  $^8\text{Be}$  GDR (arxiv:2308.06473)



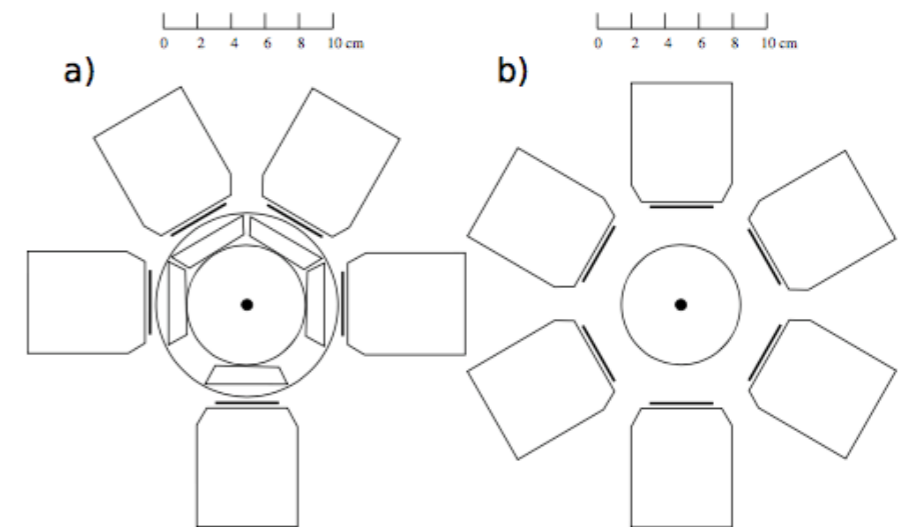
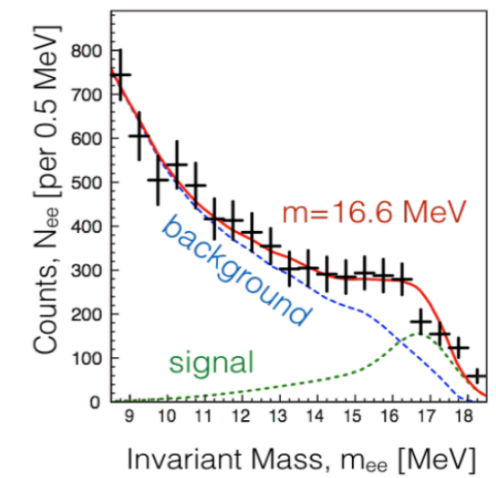
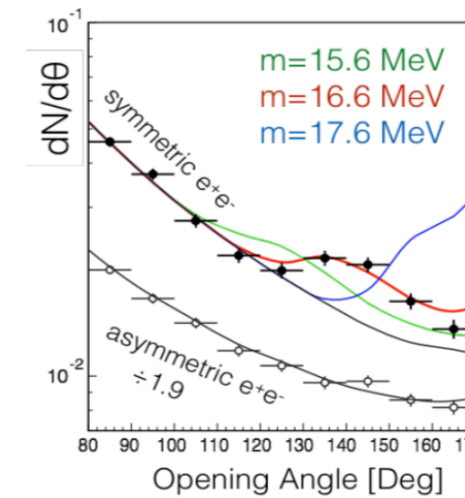
# Muon g-2

- Combined result halves previous uncertainties
- Remaining data-taking will reduce by additional 2x
- Good agreement with previous measurements,  $5\sigma$  tension with *2020* theory.
- Theory now being carefully evaluated: dispersive vs lattice
- Resolving this could strongly reduce tension



# X17

- ATOMKI group sees anomaly in  $^8\text{Be}$ ,  $^4\text{He}$ ,  $^{12}\text{C}$
- Signal rises and falls with proton beam energy
- Appears only for symmetric pairs
- Persists in original 5-fold and 6-fold detector geometry
  - Most detector angles are the same, but the resonance angle moves with species
  - Resonance within acceptance -- not edge effect
- Compatible with axial vector boson decay
- Very incompatible with simple kinetic mixing model -- would have been seen in pion decay as well

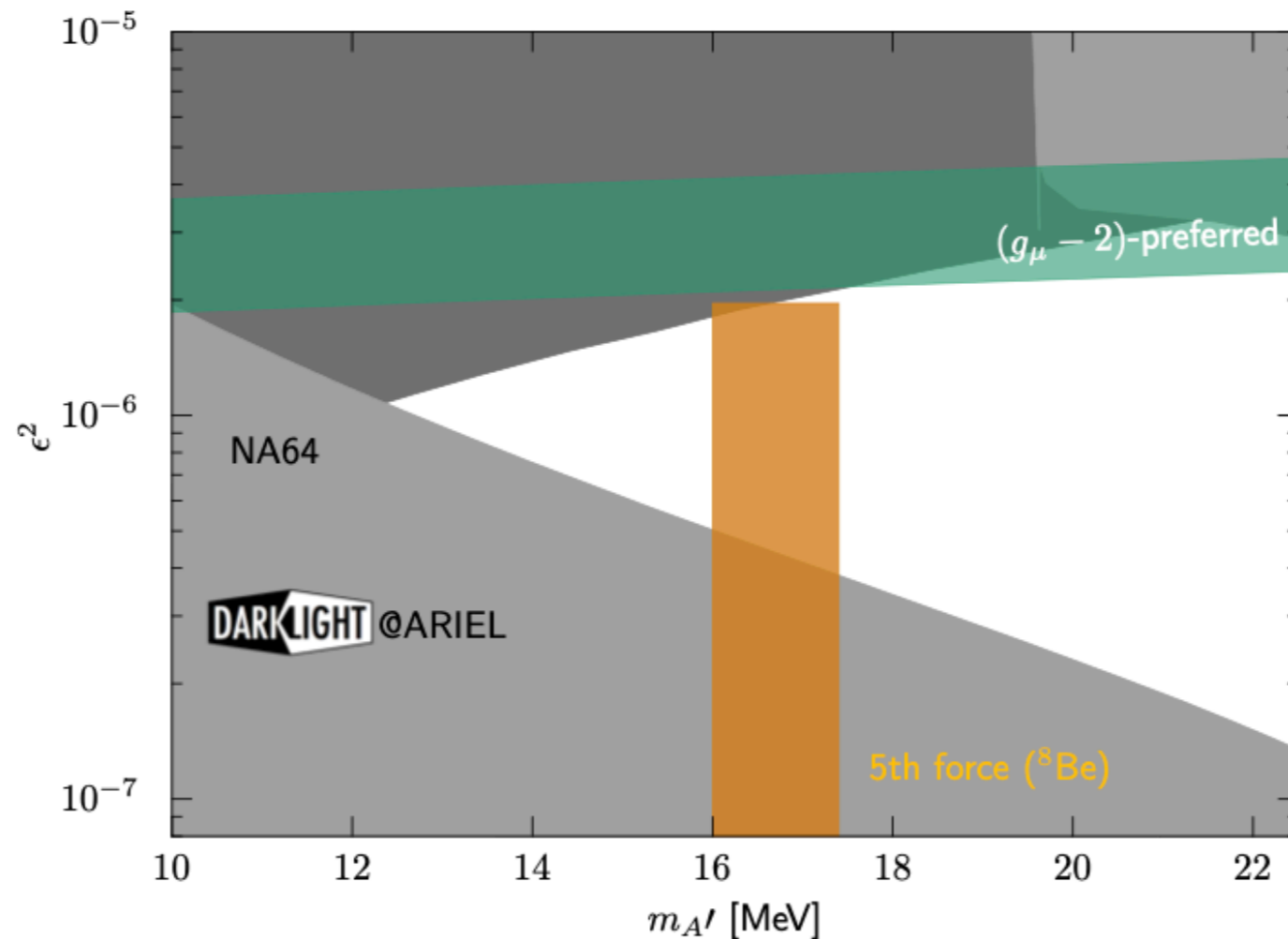


	scalar	pseudo-scalar	axial vector	vector
$^8\text{Be}$ $1^+ \rightarrow 0^+$	✗	✓	✓	✓
$^4\text{He}$ $0^+ \rightarrow 0^+$	✗	✓	✓	✗
$^{12}\text{C}$ $1^+ \rightarrow 0^+$	✓	✗	✓	✓

# Other X17 Reports

- Axial-vector particle with mass  $\sim 17\text{MeV}$  continues to be viable, but SINDRUM, PIENU constrain it heavily ([arXiv:2306.15077](https://arxiv.org/abs/2306.15077))
- VINATOM experiment (with ATOMKI involvement) sees it in  $^8\text{Be}$  decay ([arxiv:2401.11676](https://arxiv.org/abs/2401.11676))
- Miller and Zhang ([arxiv:2008.11288](https://arxiv.org/abs/2008.11288)): axial-vector X17 should be produced in direct proton capture:  
 $^7\text{Li}(p, e^+e^-)^8\text{Be}$  off-resonance
- ATOMKI group sees it (with caveats): ([arxiv:2205.07744](https://arxiv.org/abs/2205.07744))
- X17 should be visible in GDR ([arxiv:2305.09066](https://arxiv.org/abs/2305.09066))
- ATOMKI group sees it ([arxiv:2308.06473](https://arxiv.org/abs/2308.06473))

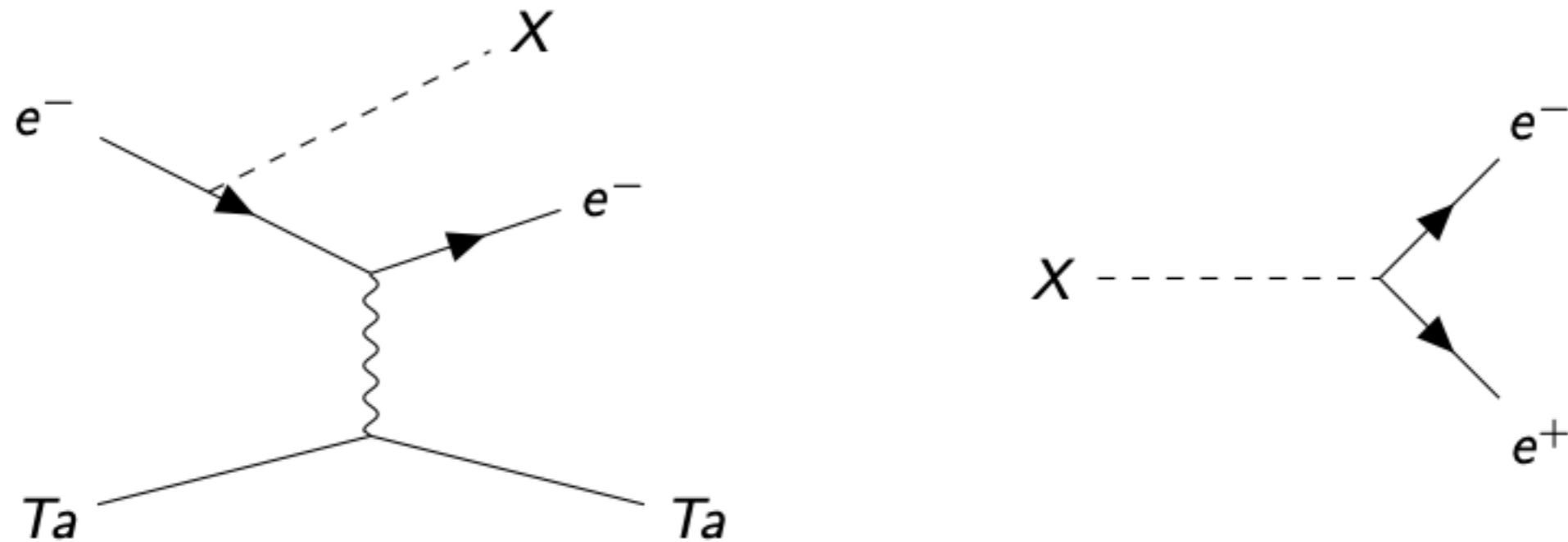
# Probing Leptonic Coupling



- X17 allowed leptonic coupling region is accessible in fixed target
- $(g_{\mu}-2)$  band nearby as well -- and will shift downward if theory tension is reduced.



# Producing a Dark Boson



- Probe leptonic coupling directly:
- Look for peak in  $e^+e^-$  invariant mass spectrum
- Requires low energy, high current  $e^-$  accelerator

# DarkLight Collaboration

Arizona State University, USA

Hampton University, USA

Thomas Jefferson National Accelerator Facility, USA

Laboratory for Nuclear Science, MIT, USA

Saint Mary's University, CA

Center for Frontiers in Nuclear Science, Stony Brook University, USA

TRIUMF, CA

University of British Columbia, CA

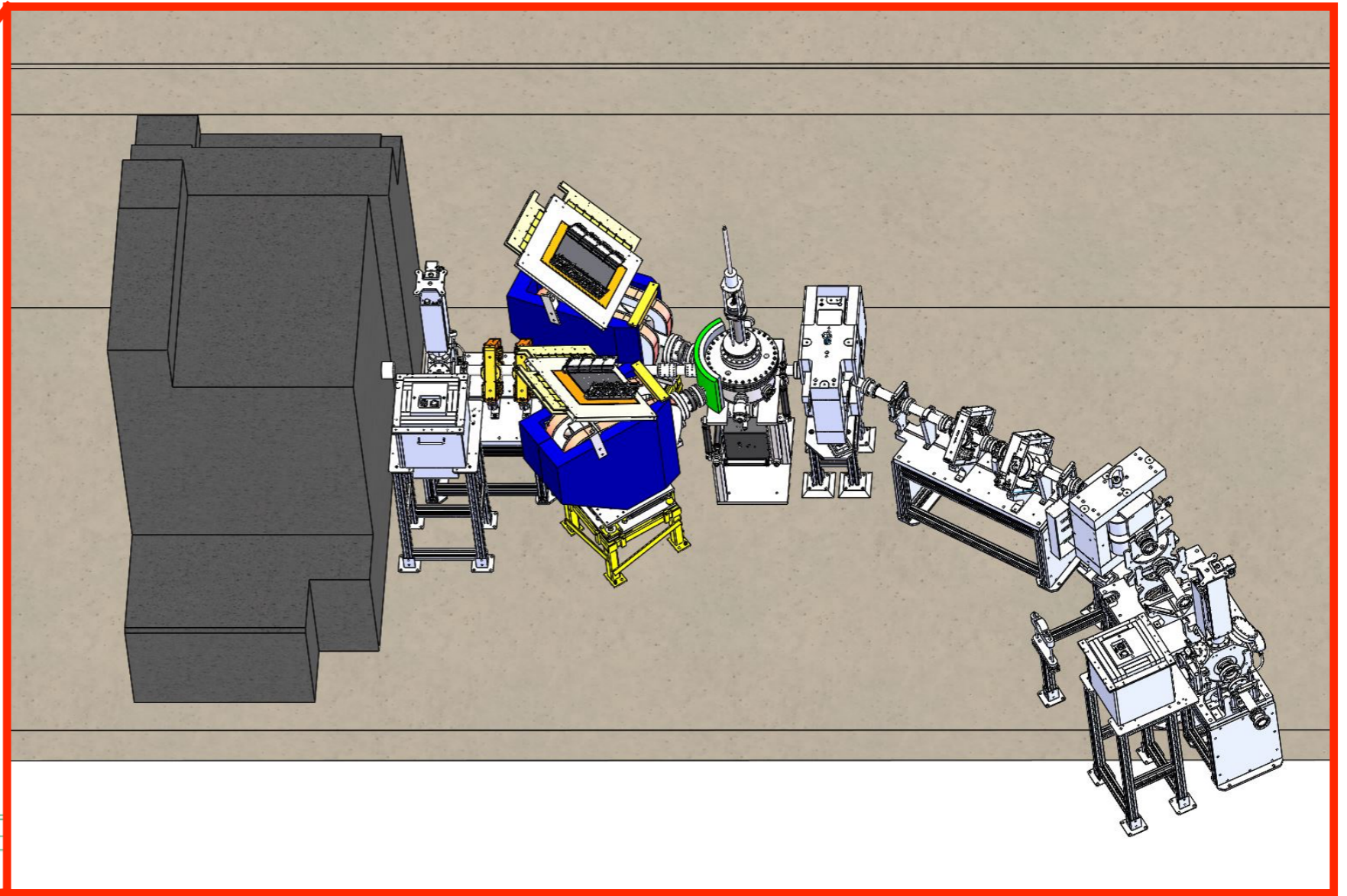
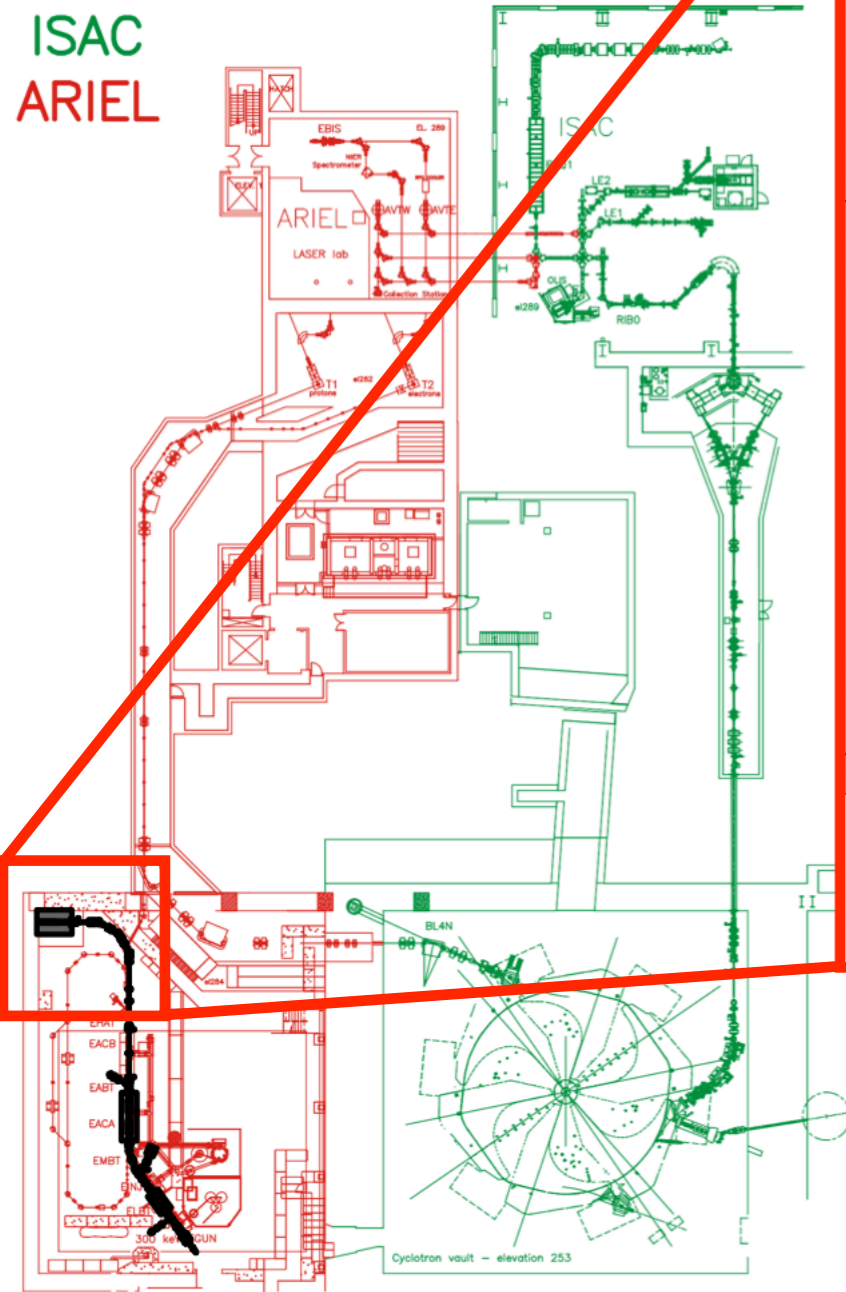
University of Manitoba, CA

University of Winnipeg, CA

University of Zagreb, HR

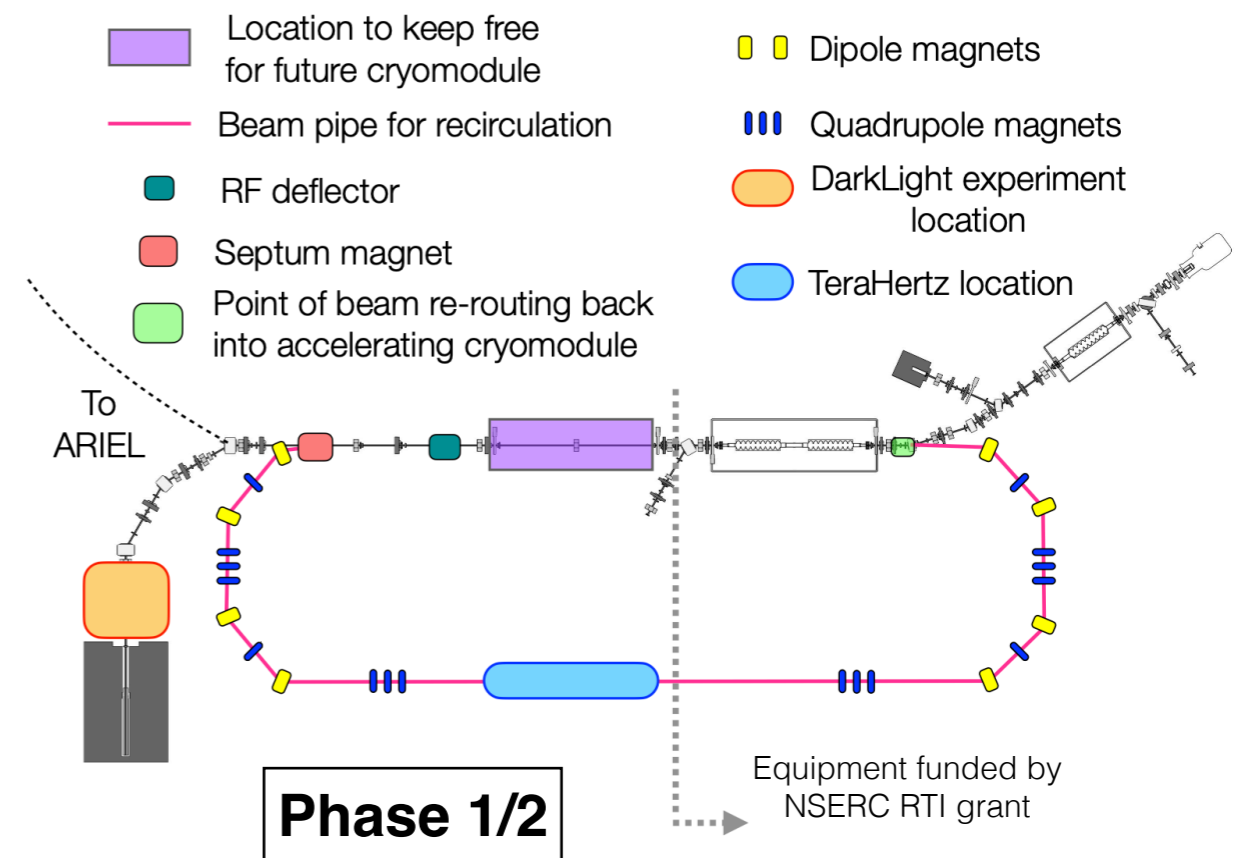
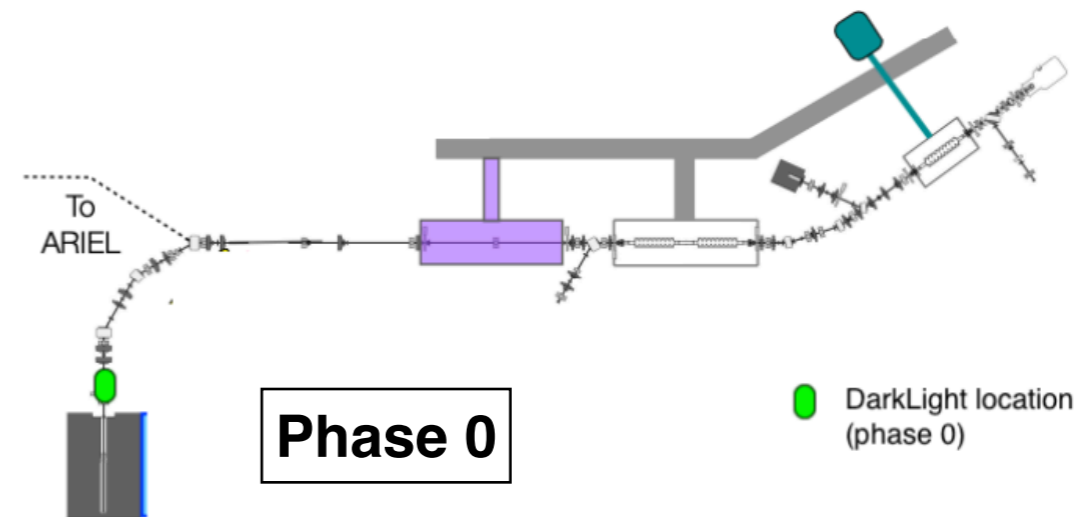
Mainz University, DE

# DarkLight at ARIEL



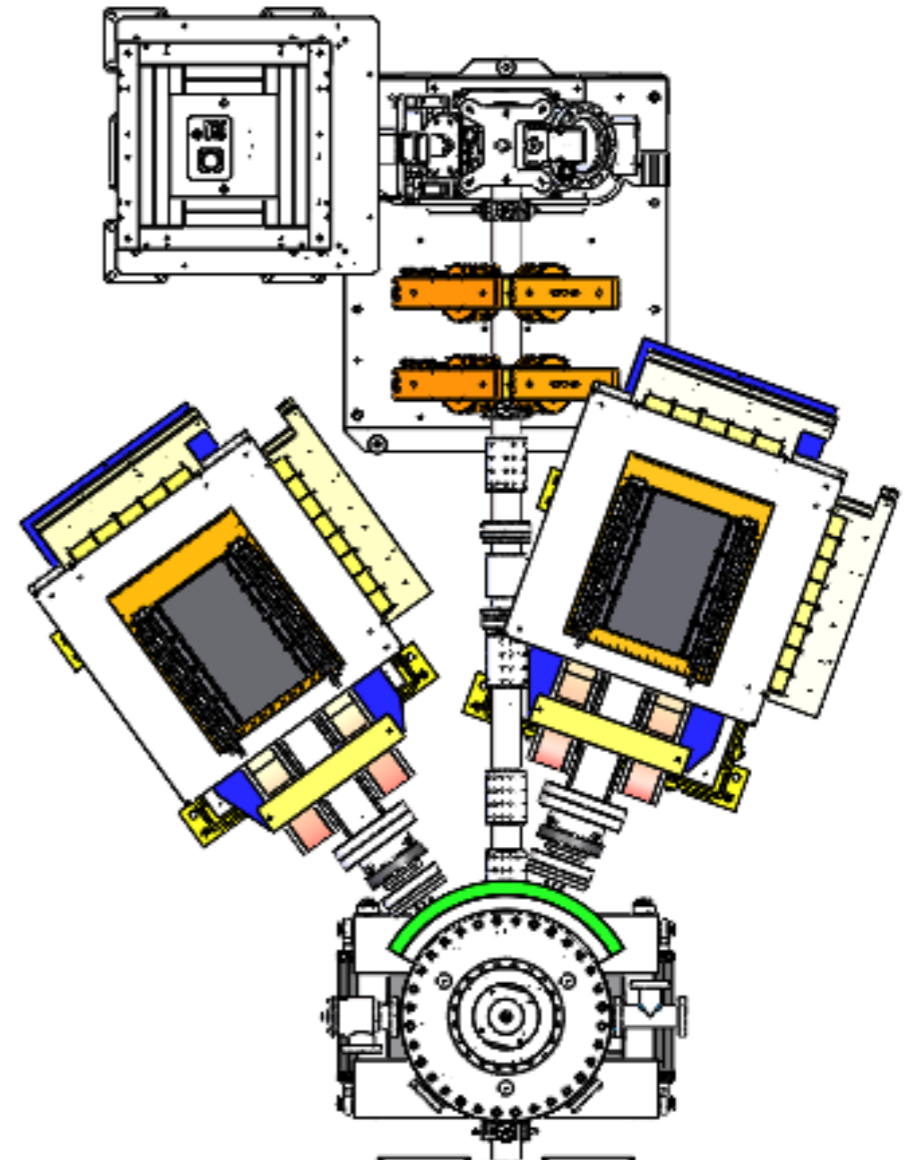
# DarkLight Phased Running

- Phase 0:
  - Single user mode @31 MeV
  - minor changes to optics, existing beam dump
- 450k CAD NSERC for half of recirculating ring upgrade
- Phase 1:
  - Single user mode ~50 MeV
- Phase 2: (~2027+)
  - Multi-user mode ~50 MeV



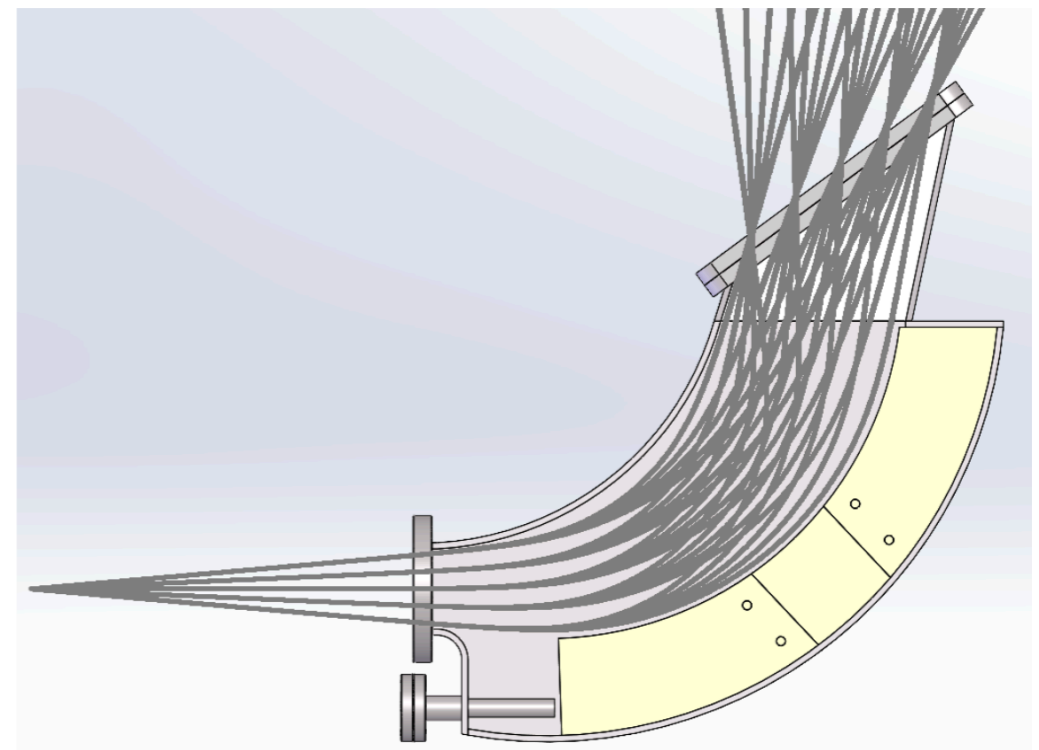
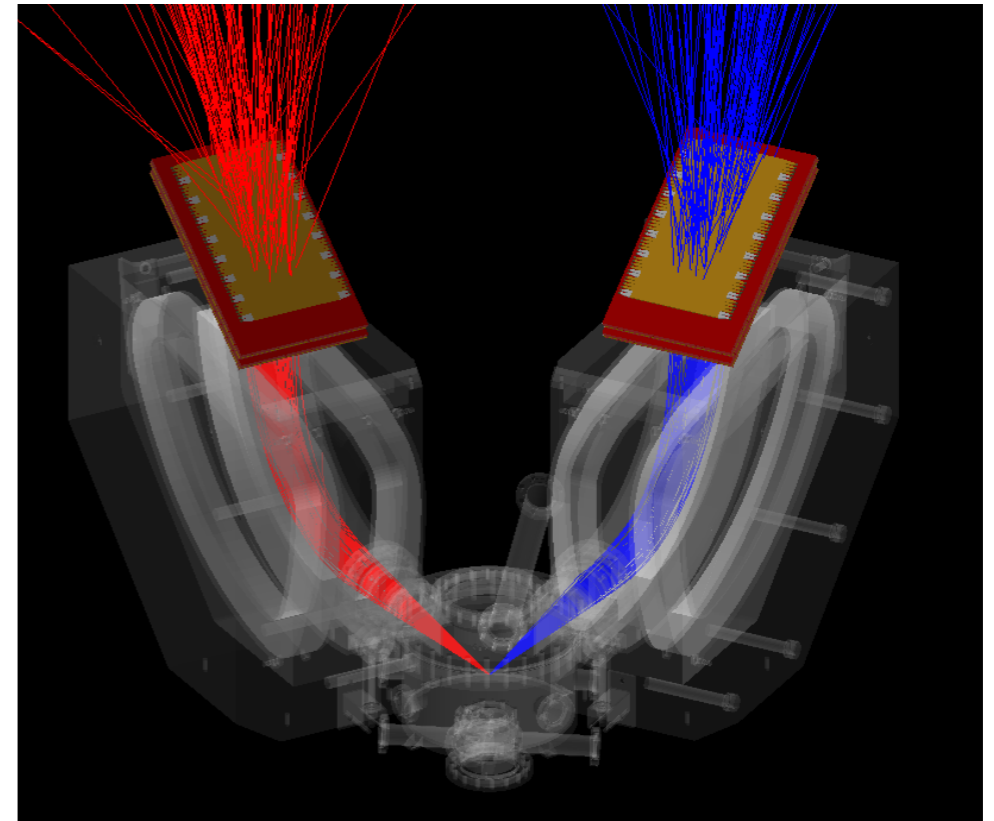
# Beamline and Chamber

- Target ladder: 10,5,1,0.5  $\mu\text{m}$  Ta foil + empty
  - 8W heating from 300 $\mu\text{A}$  beam @ 30 MeV
- Permanent beam quadrupole magnets downstream allow spectrometer arm at small angle



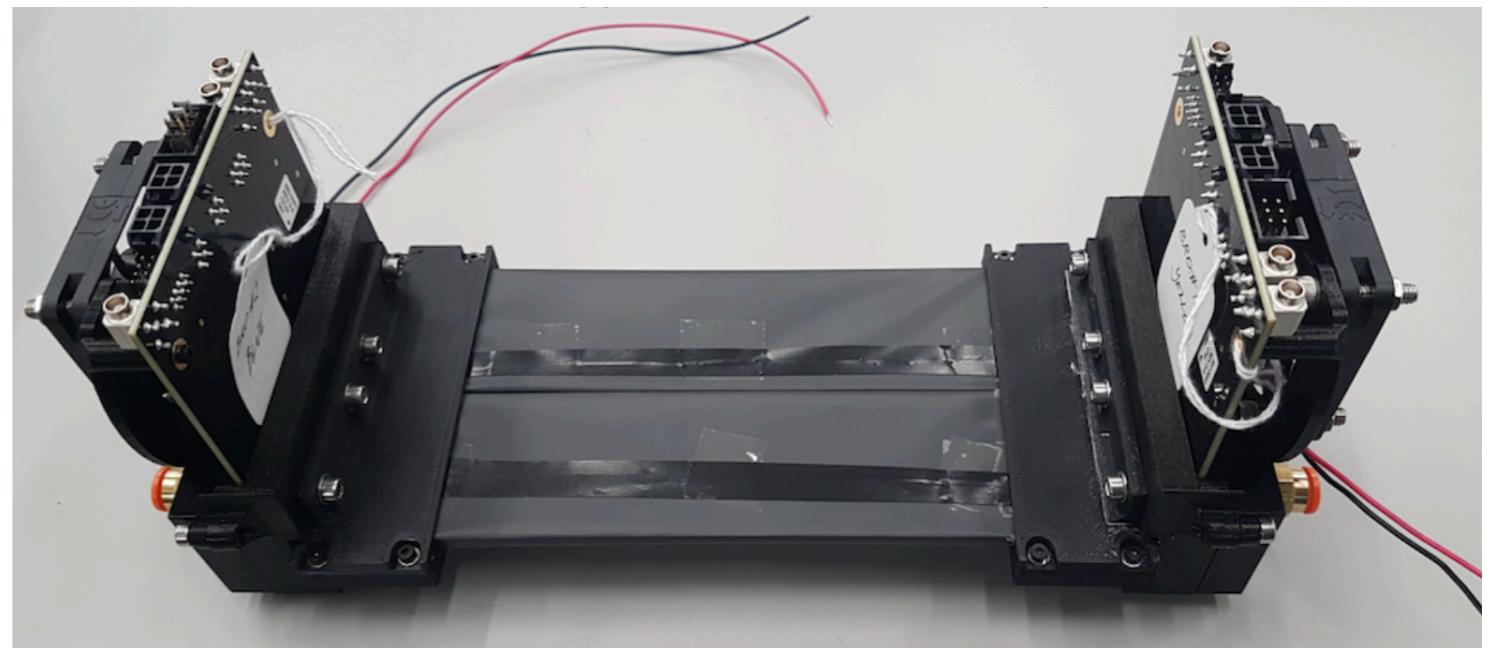
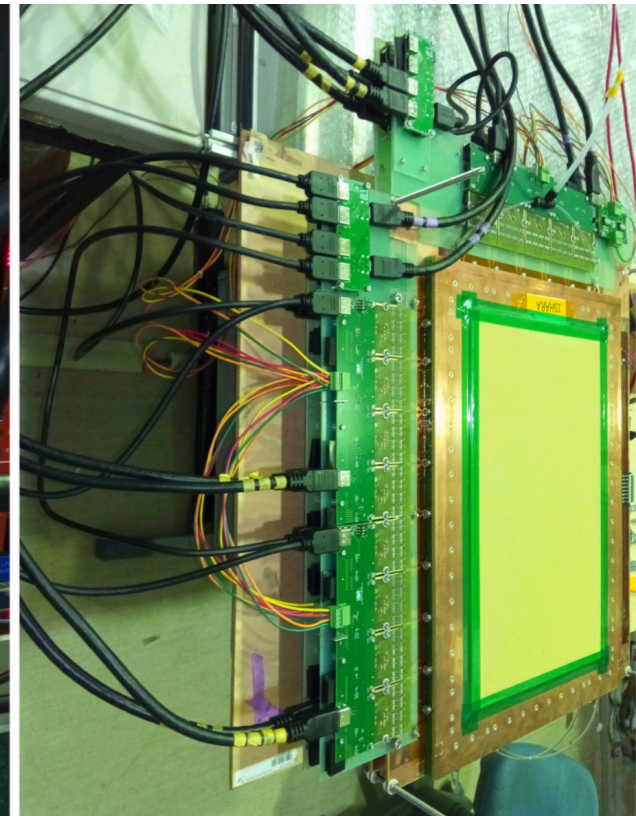
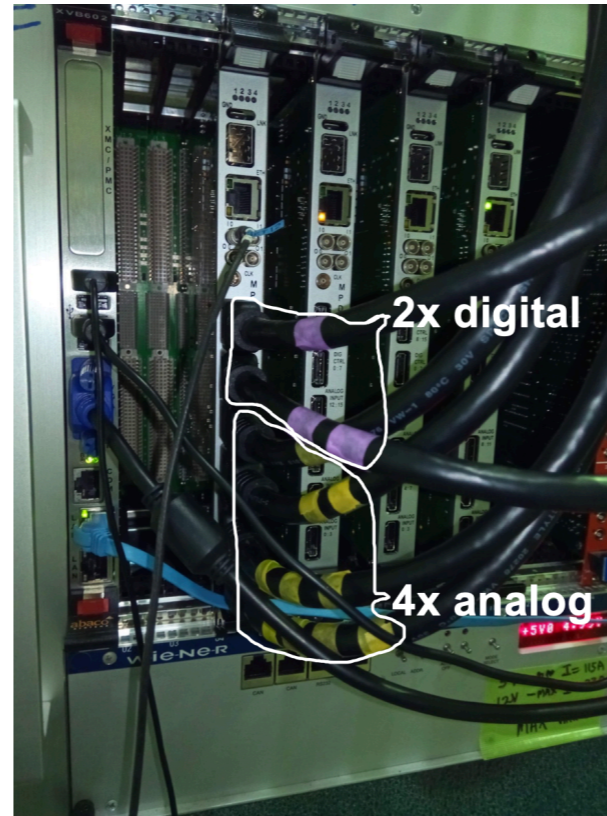
# Spectrometers

- Engineering model integrated into simulation chain allows detailed optimization
- PEEK inserts added inside vacuum to reduce elastic e<sup>-</sup> background
- Chamber and magnets on order, will be assembled at MIT Bates
- Assembly schedule limited by long leadtime on magnets

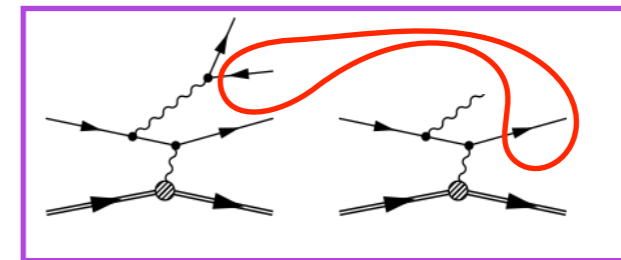
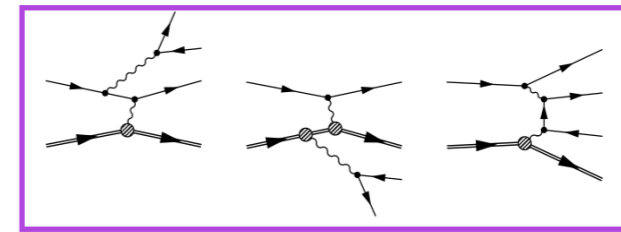
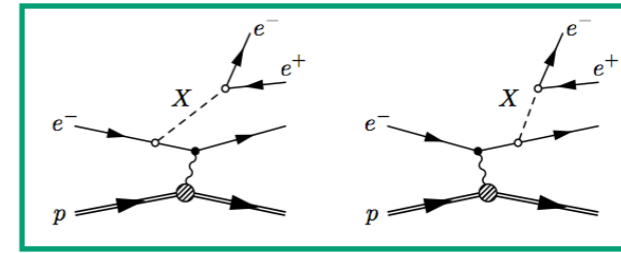
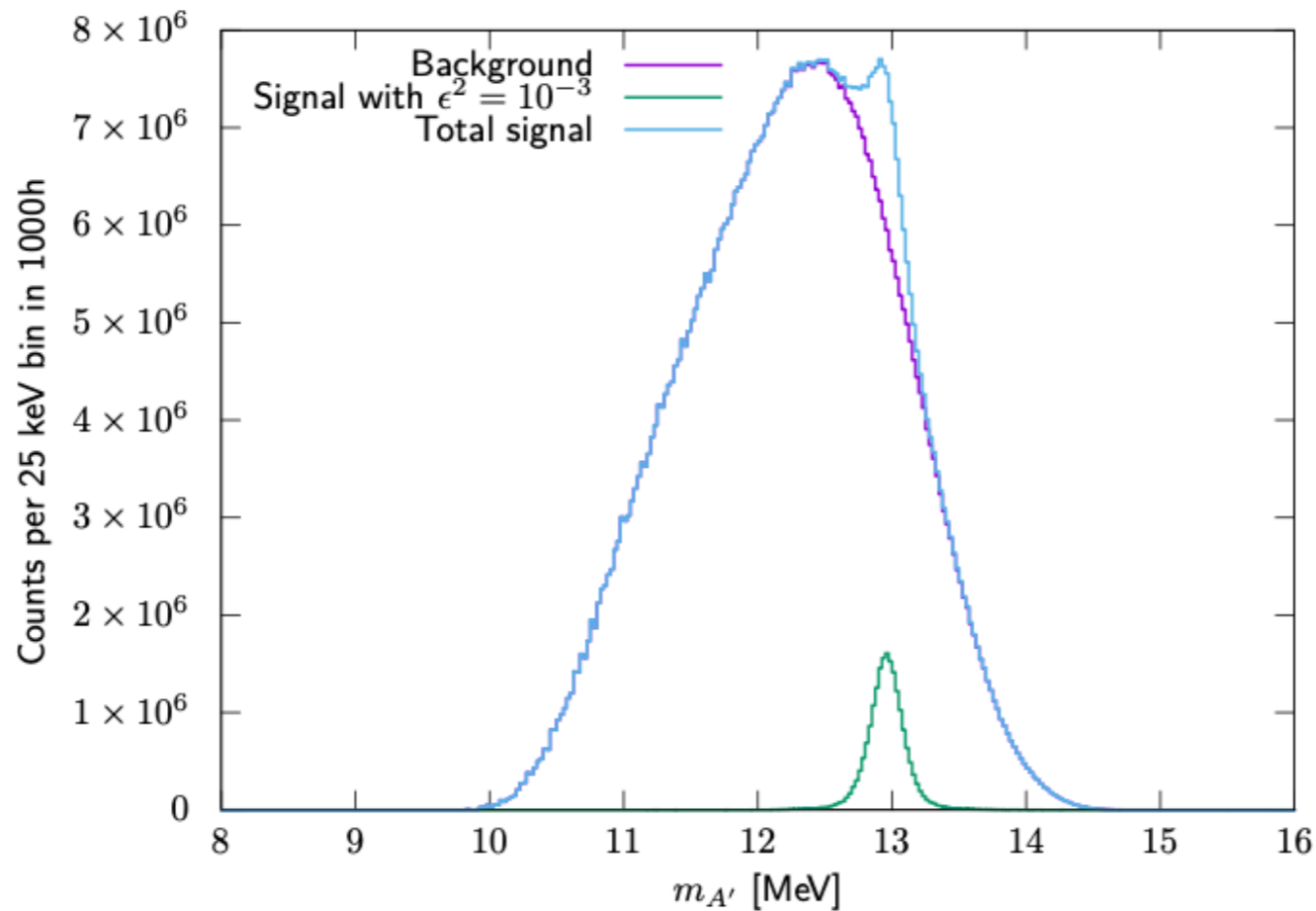


# Detectors

- 25x40cm<sup>2</sup> triple-GEM focal plane detectors built by Hampton
- APV+MPD4 readout
- 2 at TRIUMF, 2 at JLab for commissioning
- Segmented scintillator hodoscope triggers
- SiPM readout, resolution < 200ps
- Under construction at TRIUMF



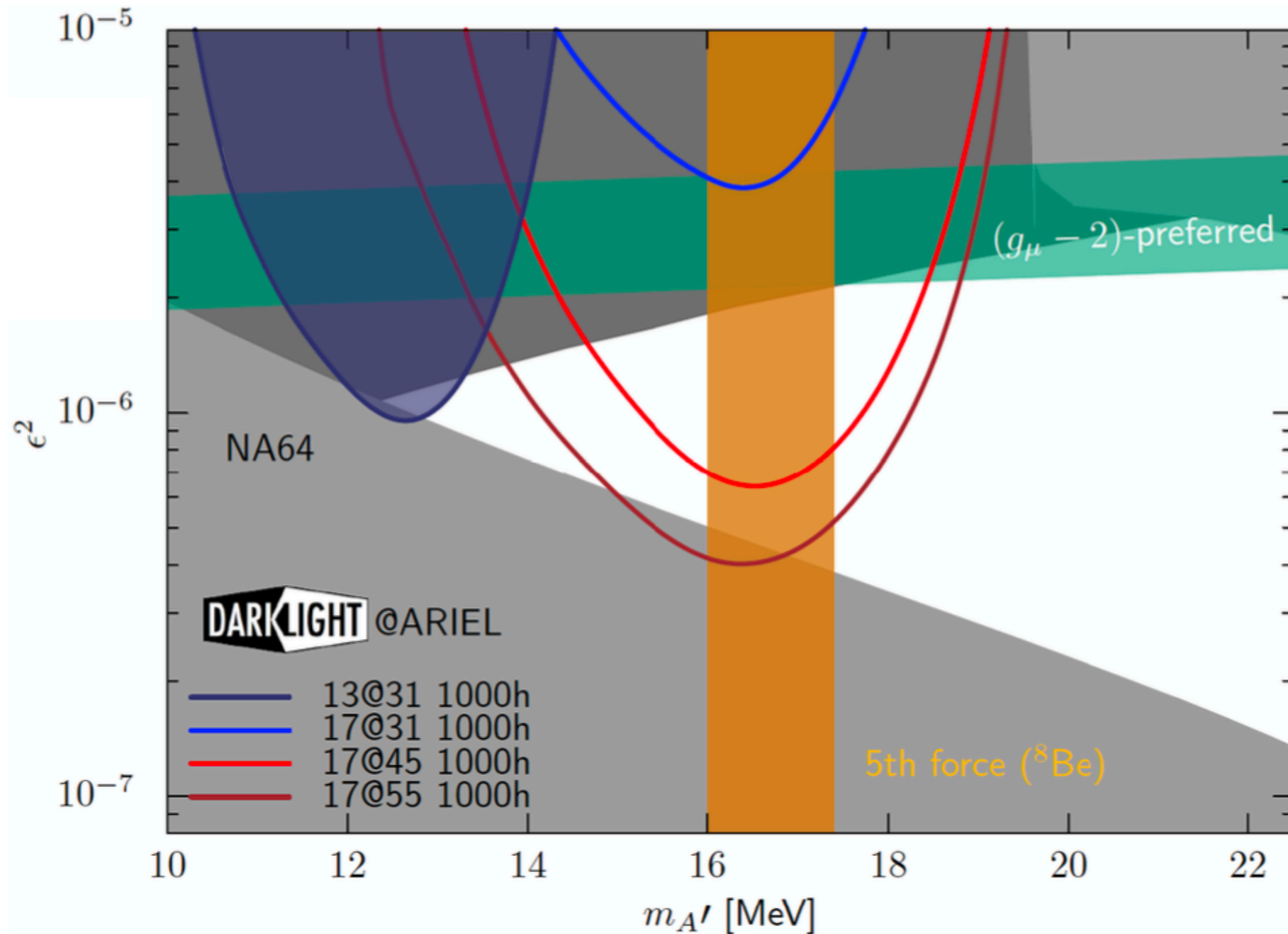
# Analysis



- Bump-hunt:  $X \rightarrow e^+e^-$  signal under  $\gamma \rightarrow e^+e^-$  SM background
  - $\gamma$  from scattering or radiative terms -- rate scales with  $\mathcal{L}$
  - Combinatoric  $e^+ + \text{any } e^-$  scales with  $\mathcal{L}^2$
- At high  $\mathcal{L}$ , combinatoric dominates  $\text{FOM} \sim \frac{S}{\sqrt{B}}$



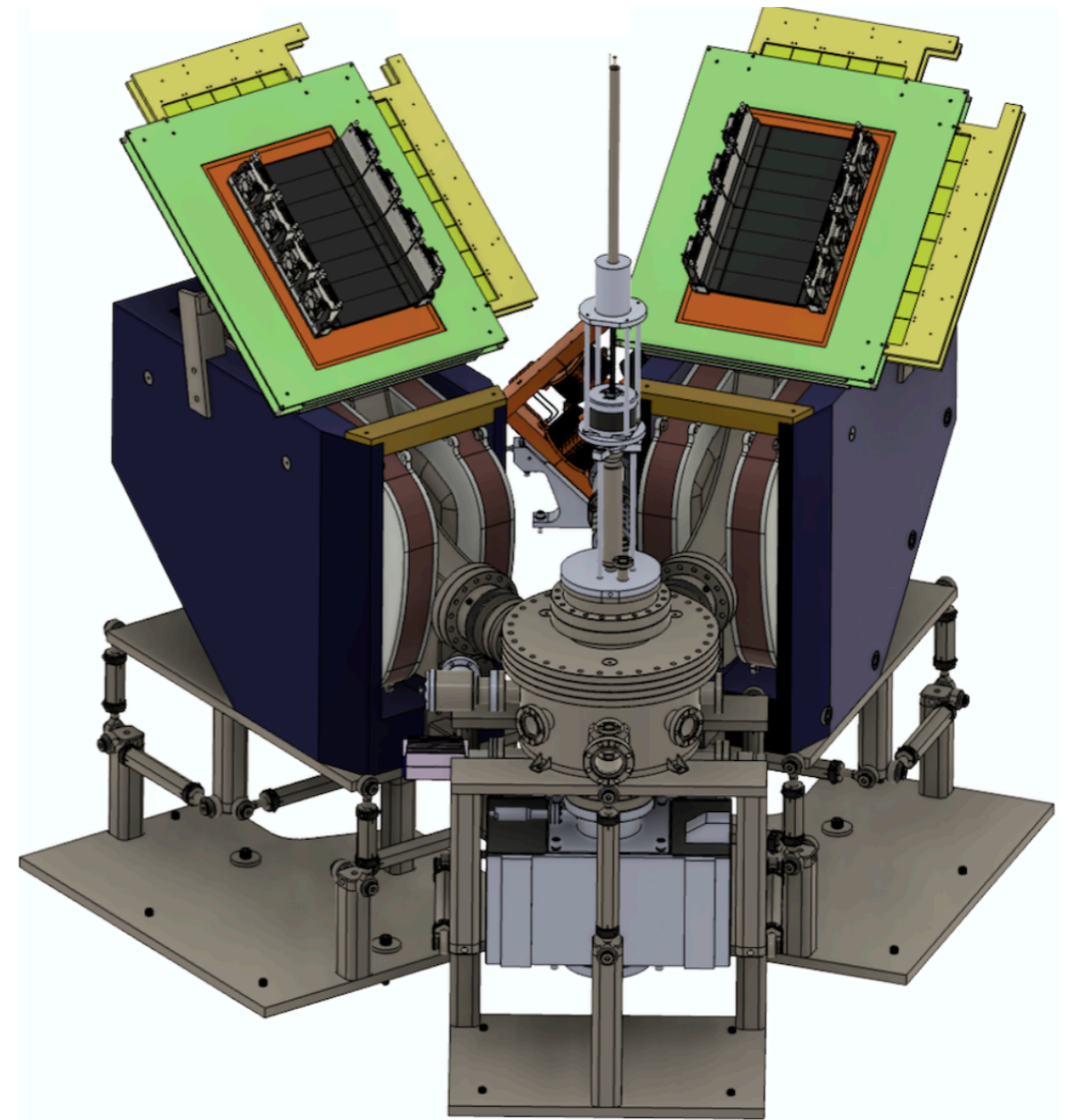
# Projected Reach



- Phase 0 projection (conservative spectrometer res.) in shaded region
- Red curves accessible with energy upgrade
- $g-2$  band assuming dispersive theory calc.

# Timeline of Detector

- Design of major elements completed
- Constructing and staging components now:
  - First arm GEM set on site, other at JLab
  - Trigger hodoscopes under construction and testing @ TRIUMF
  - Summer: target chamber arrives @ TRIUMF
  - Fall: magnets arrives @ MIT
- Start integration and testing in late summer.

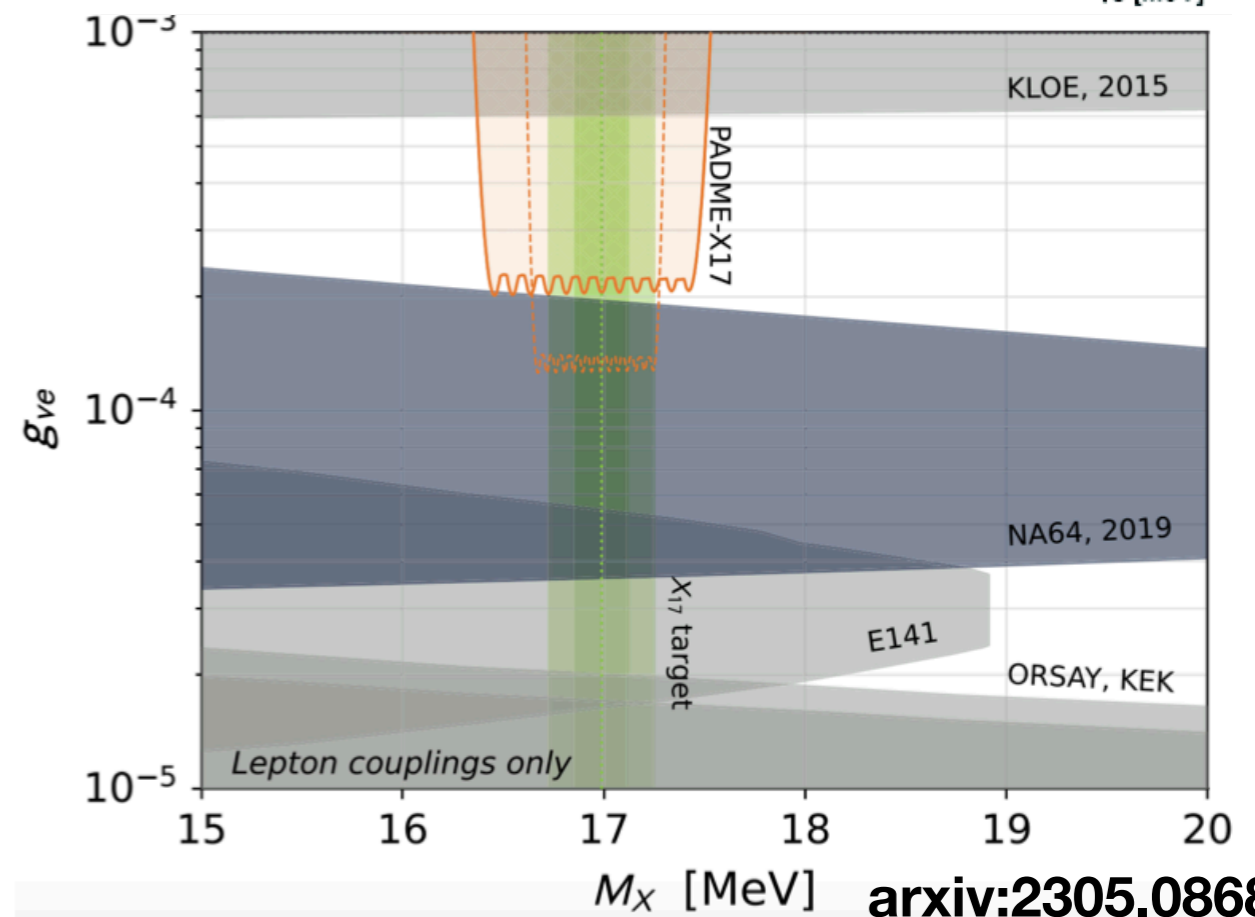
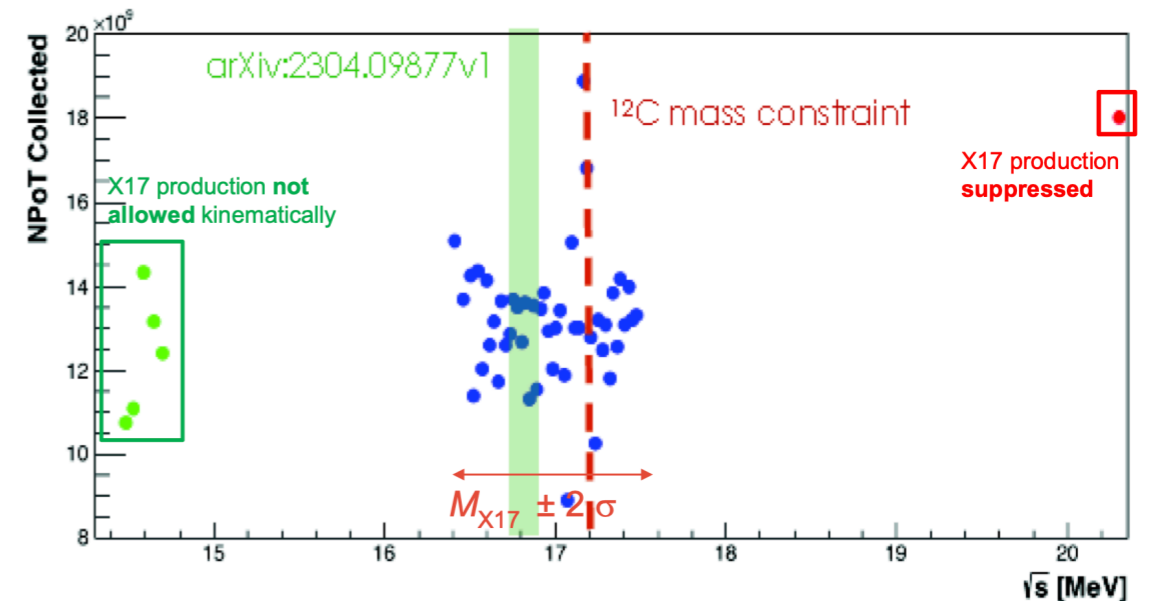


# Other experiments

- Resonance in Nuclear Decays:
  - COPE - not clear
  - **MEGII - 8Be ran in 2023, blinded**
  - Melbourne TPC - no timeline yet
  - **Montreal/Project X17 - 8Be run in 2023+, blinded**
  - New JEDI - not clear
  - *et al.*
- Dark-Photon Specific:
  - APEX - probably can't reach
  - HPS - possible redesign to reach
  - LDMX - begins 2024+, closes from below. data hungry
  - MAGIX - begins 2025+
  - Mu3e - begins 2025+
  - NA64 - can modify in 2024 if other results encourage
  - **PADME - ran in 2022. blinded.**
  - PRad - modified to close the gap, approved in 2023
  - *et al.*
- General-Purpose Accelerator:
  - Belle II - stats in 2025 or later
  - **FASER - first prelim results now, closes from below.**
  - LHCb - stats in 2026 or so

# PADME

- $e^+e^- \rightarrow \gamma A'$  experiment converted to look at low mass  $e^+e^-$  final states:
  - Magnet off
  - $e^+$ /bunch reduced
- Data taken in 2022, signal region blinded
- As of late 2023: preparing to analyze close sidebands of signal region



[arxiv:2305.08684](https://arxiv.org/abs/2305.08684)

**WPCF 2023 presentation**

# Summary

- X17 anomalies continue to generate strong interest
- Multiple experiments underway, several with results anticipated soon:
  - MEGII, Montreal → confirmation of nuclear decay
  - PADME, Belle II → probe leptonic couplings
- DarkLight:
  - Trigger scintillators, half of GEM modules at TRIUMF
  - Chamber and dipoles in production, final components arrive this fall
  - Expect to install by end of 2024
  - Phase 0 data-taking to follow

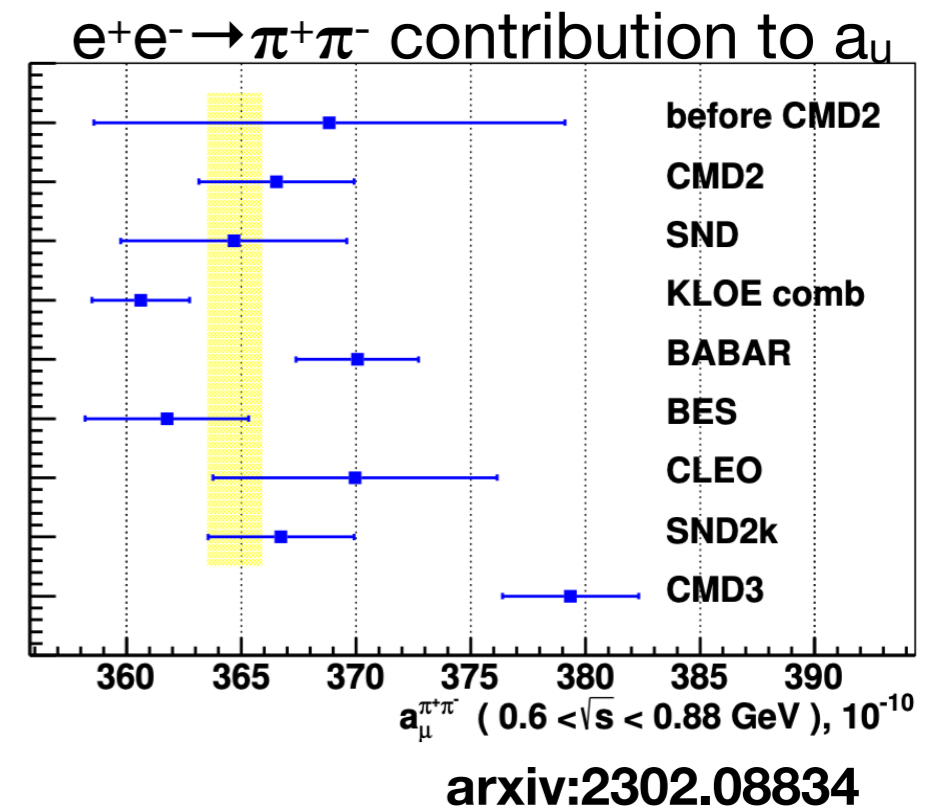
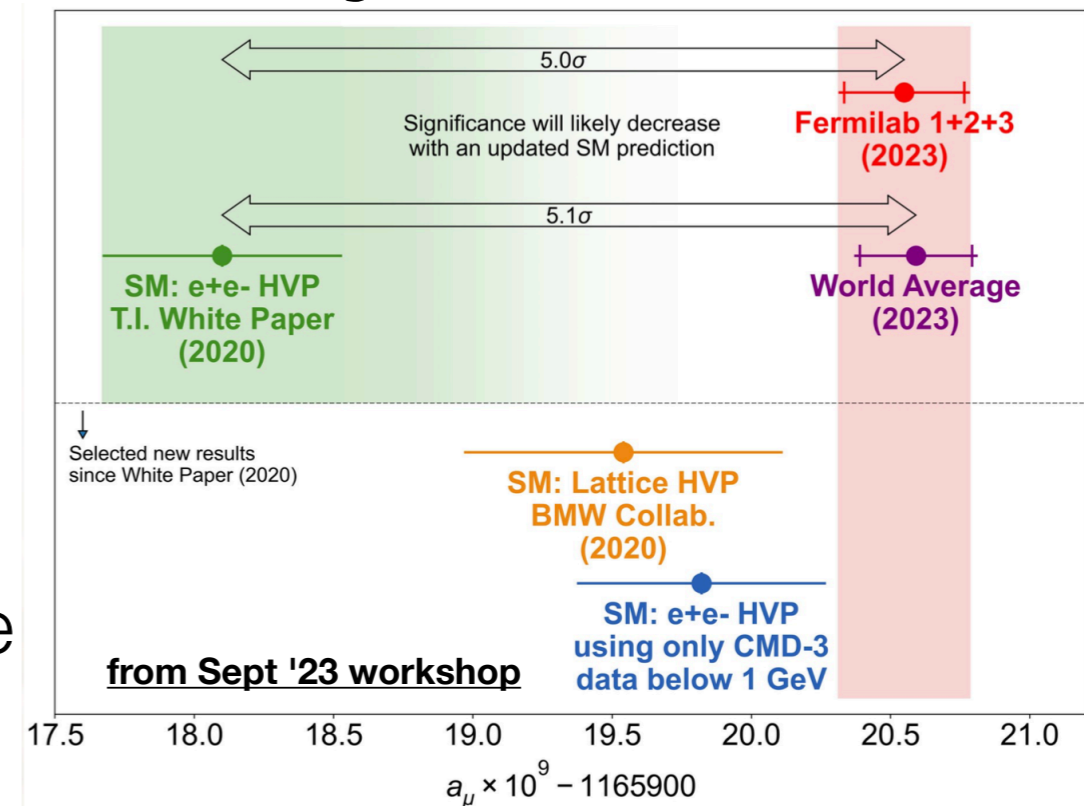


# Low-Mass Anomalies

- ATOMKI X17 8Be GDR ([arxiv:2308.06473](https://arxiv.org/abs/2308.06473))
  - and  $^{12}\text{C}$  ([arxiv:2209.10795](https://arxiv.org/abs/2209.10795)), 4He, 8Be resonance
- FNAL g-2 combined result ([arxiv:2308.06230](https://arxiv.org/abs/2308.06230))
- KTeV  $\pi^0 \rightarrow e^+e^-$  enhancement ([arxiv:2212.06453v3](https://arxiv.org/abs/2212.06453v3))
- Neutron lifetime ([PT Du et al 2020 J. Phys.: Conf. Ser. 1506 012004](https://arxiv.org/abs/2001.01200))
- King Plot SM combined analysis ([arxiv:2111.01429](https://arxiv.org/abs/2111.01429))
- Cosmic  $^7\text{Li}$  underabundance ([arxiv:1510.08858](https://arxiv.org/abs/1510.08858))  
( $1 < M_\chi < 20 \text{ MeV}$ , but wants  $\tau \gtrsim 100 \text{ s}$ )

# Muon g-2 Theory

- 2021: Tension between predictions from Lattice and dispersive theory
- BMW '21 closer to measurement, but with caveats, and was not used in PDG average.
- 2023: series of new, precise dispersive datasets agree with existing data
- except CMD-3 measurement of  $e^+e^- \rightarrow \pi^+\pi^-$  ([arxiv:2302.08834](https://arxiv.org/abs/2302.08834)), in strong disagreement with all previous measurements.
- Muon g-2 Theory Initiative is looking closely at the result, and other theory issues -- next workshop in September '24



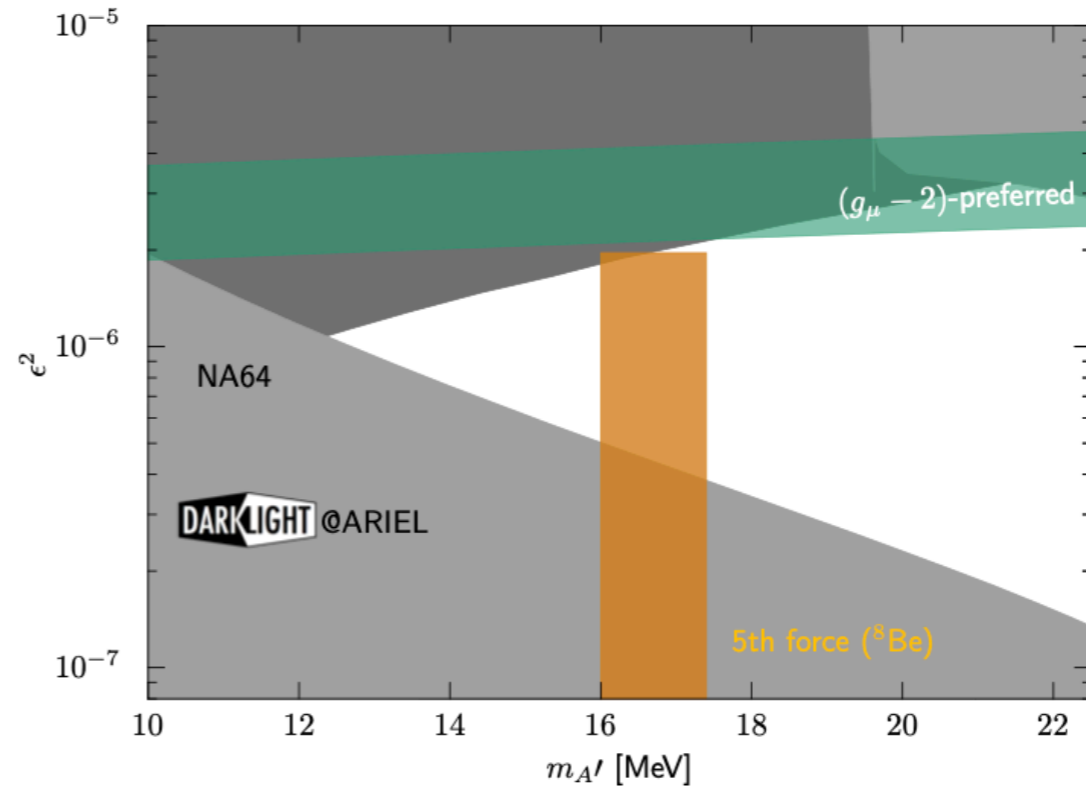
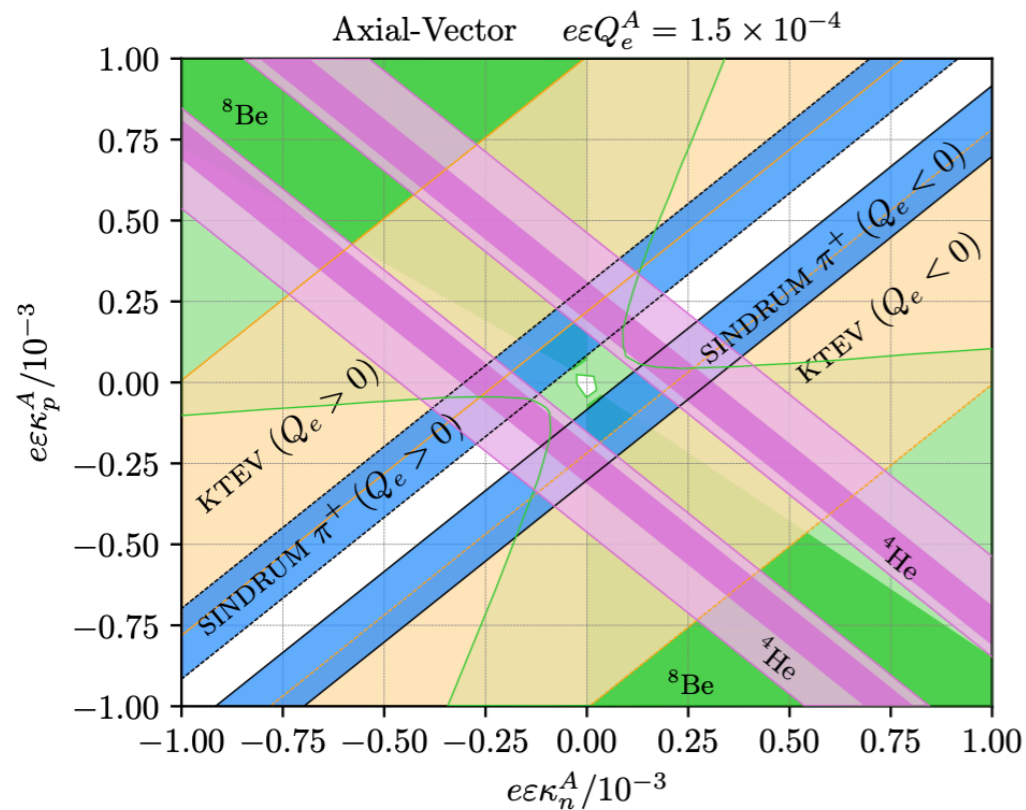


# Protophobia?

- Generalized new force could have flavor-dependent coupling:

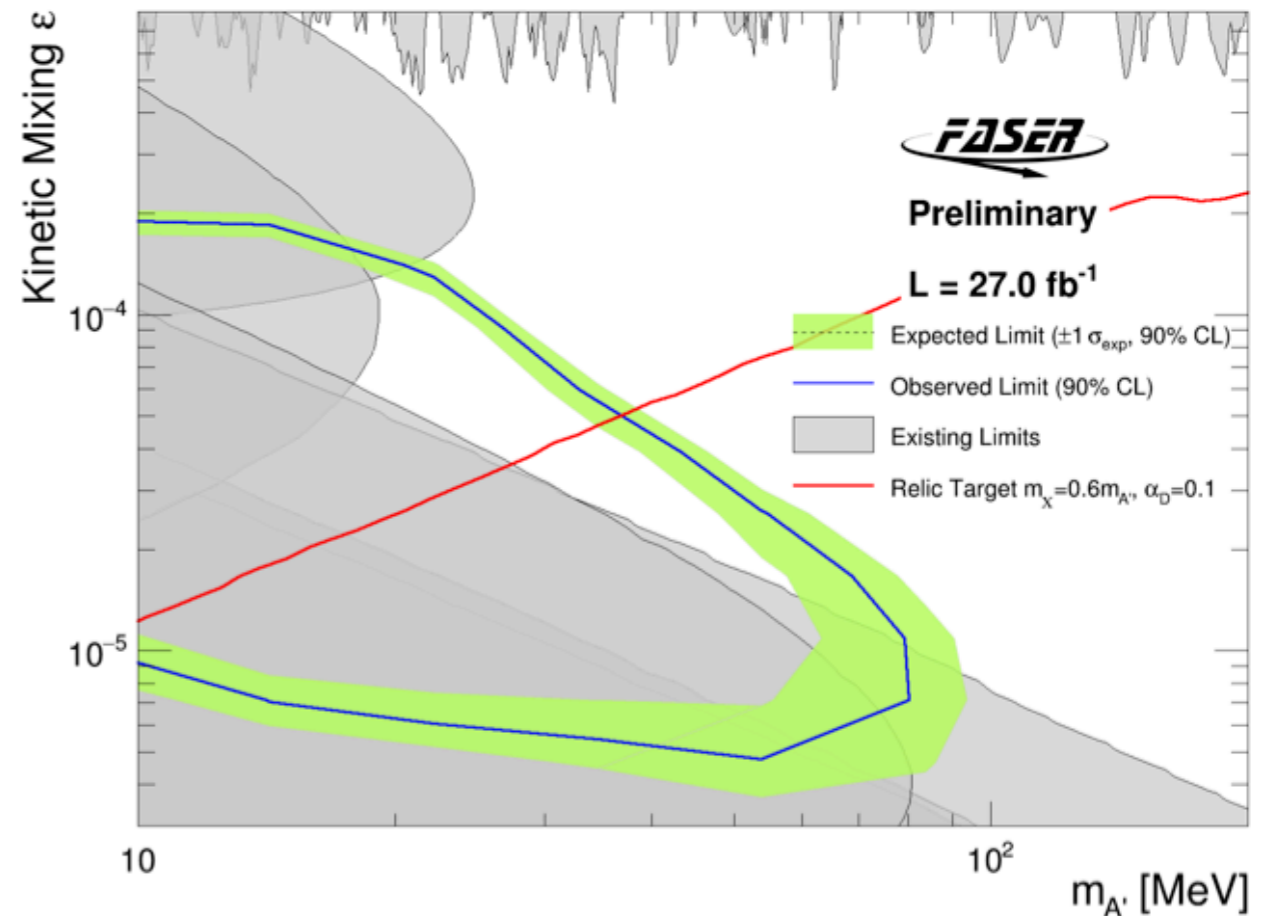
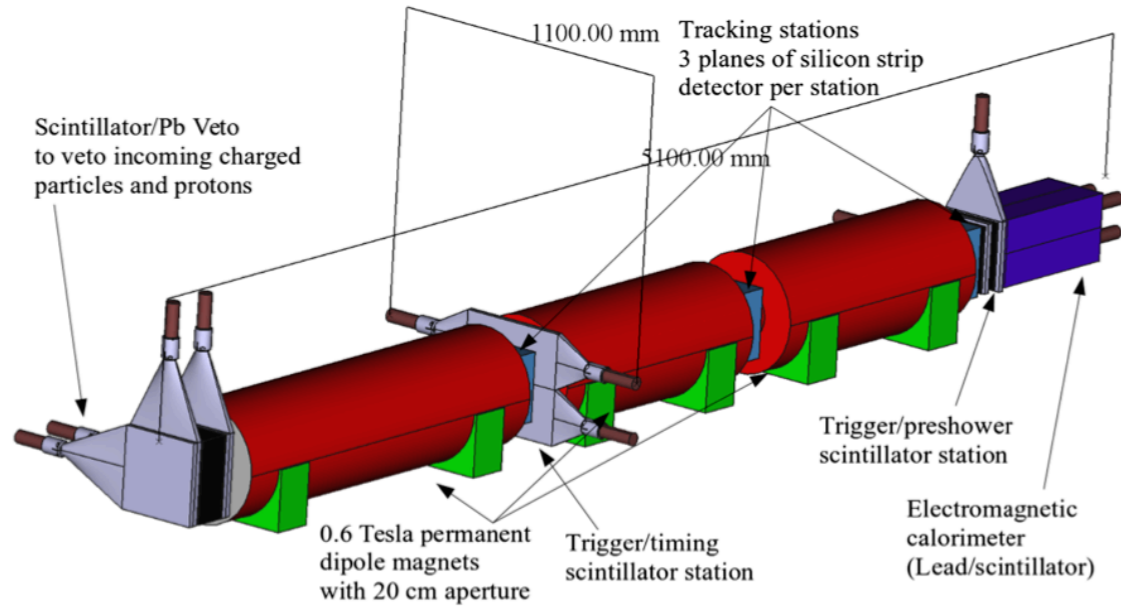
$$X^\mu (\Sigma_f e \epsilon_f \bar{f} \gamma_\mu f)$$

- Moderately protophobic coupling combinations allow X17 to evade existing particle constraints



- $|\epsilon_p/\epsilon_n| < 8\%$  -- similar scale as for  $Z^0$
- **Purely leptonic production** provides an efficient way to probe

# FASER



- ForwArd Search ExpeRiment, 480m downstream of ATLAS at LHC
- ECAL + Tracking stations with long dipole magnets
- Look for boosted  $A'$  decay to  $e^+e^-$  inside FASER volume.
- Prelim 27fb-1 from 2022 run closes/double-covers low-coupling

**arXiv:2305.08665**

# Spectrometer details

- Up to 35 MeV central momentum, 0.38 T field
- Updated parameters using full detector simulation:
  - $\pm 1.35^\circ$  in-plane,  $\pm 5^\circ$  out-of-plane acceptance
- $\pm 20\%$  momentum acceptance
- Mass resolution  $\sim 120$  keV
- Spectrometer arm at  $20^\circ$  ( $36^\circ$ ) for  $e^+$  ( $e^-$ ) in Phase 0 configuration