# Resolving the X17 Anomaly at JLab

GHP Workshop - March 15, 2025

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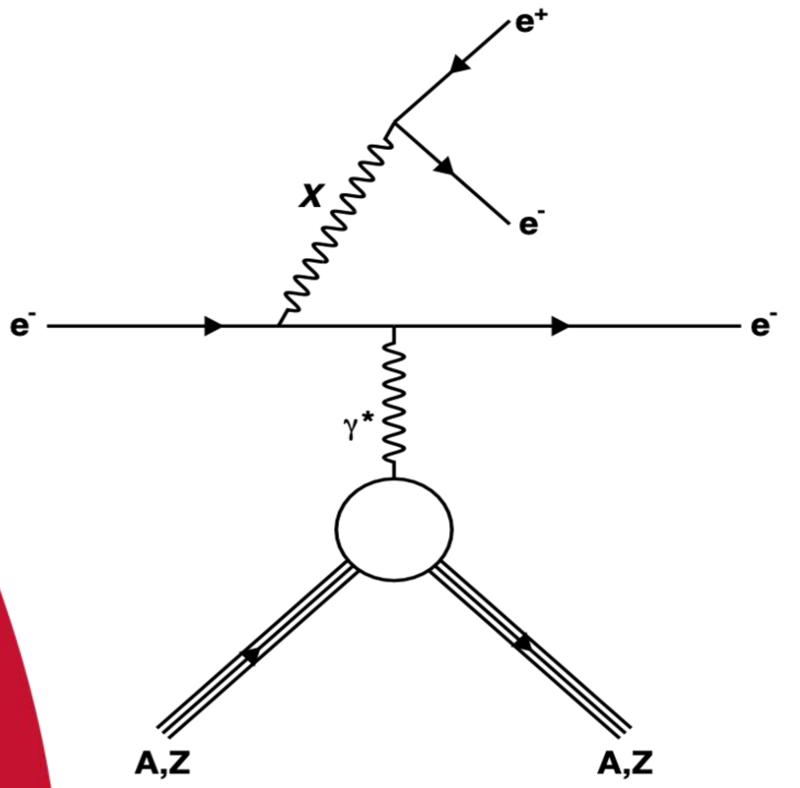
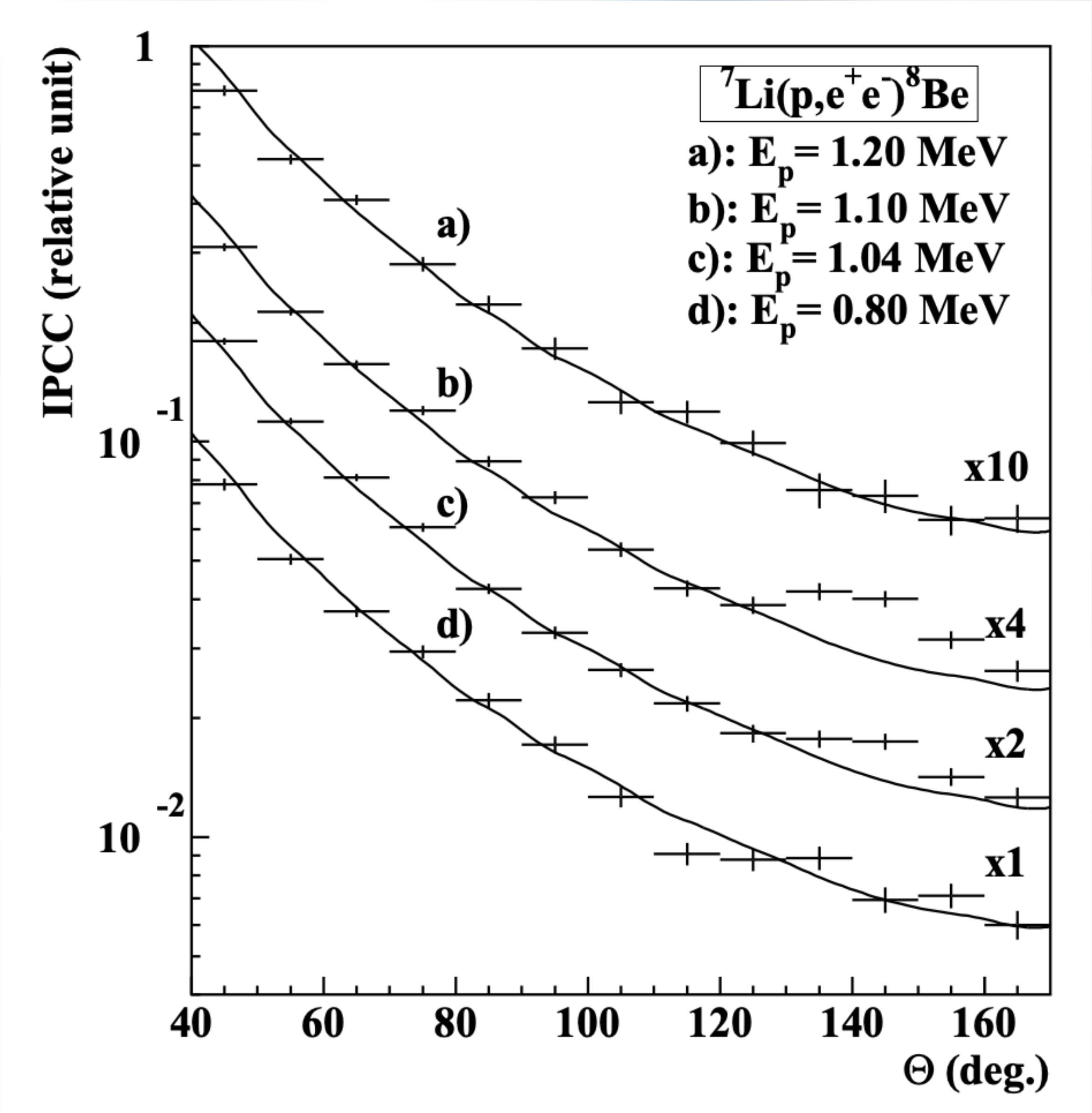


# The X17 Anomaly

# Beryllium-8 Measurement

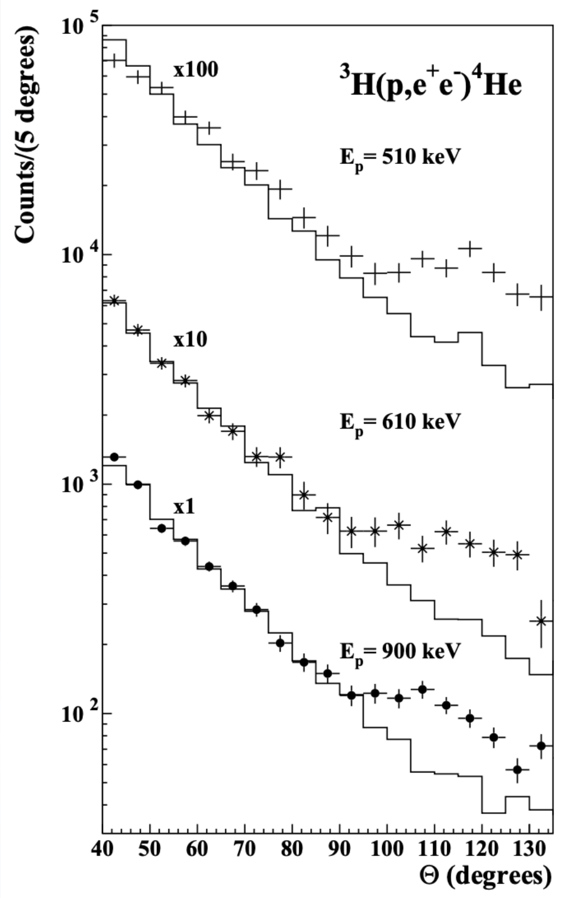
- 2015 measurement at the ATOMKI Van de Graaf generator
- Used proton capture on Lithium-7 to an excited state of Beryllium-8 to observe the e+e- spectrum
- Noted an enhancement in the angular distribution consistent with an invariant mass of ~17 MeV
- Hypothesized to be a hidden sector boson



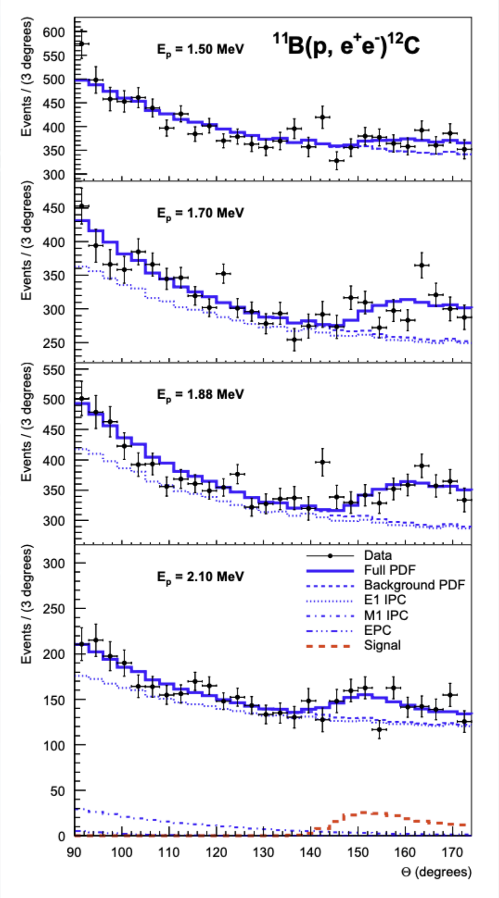

A.J. Krasznahorkay *et al.* (2015)

# Subsequent Measurements

- This measurement was repeated with:
  - Proton capture on Tritium to Helium-4
  - Proton capture on Boron-11 to Carbon-12
  - Repeated Li7->Be8
  - Repeated experiment at a different accelerator
- All of these have seen a similar enhancement
- This needs independent confirmation
- No signal has been seen by other groups




A.J. Krasznahorkay *et al.* (2021)




A.J. Krasznahorkay *et al.* (2022)

# Proposed Explanations

- “Standard” A` production Bjorken *et al. Phys.Rev.D* 80 (2009) 075018
  - Very little unexcluded phase space remaining, still possible but less likely
  - Mediates a force beyond the standard model
- “Protophobic” vector gauge boson – “X” Feng *et al. Phys.Rev.Lett.* 117 (2016)
  - Also mediates a force beyond the standard model
  - Hypothesizes a boson with flavor-dependent quark couplings such that coupling to protons (and subsequently pions) is heavily suppressed or even forbidden
  - Opens a lot more phase space, as the NA48 experiment searched for dark photons in neutral pion decays
- Hexadiquark Kubarovsky *et al. Phys.Rev.C* 111 (2025)
  - Proposed subdominant, unobserved excited state of nuclei containing alphas
  - Bound state of six scalar diquarks
  - Requires a target that contains *at least* 12 quarks to be observed and stronger in nuclei with more alpha structure
    - e.g. He4, Be8, C12

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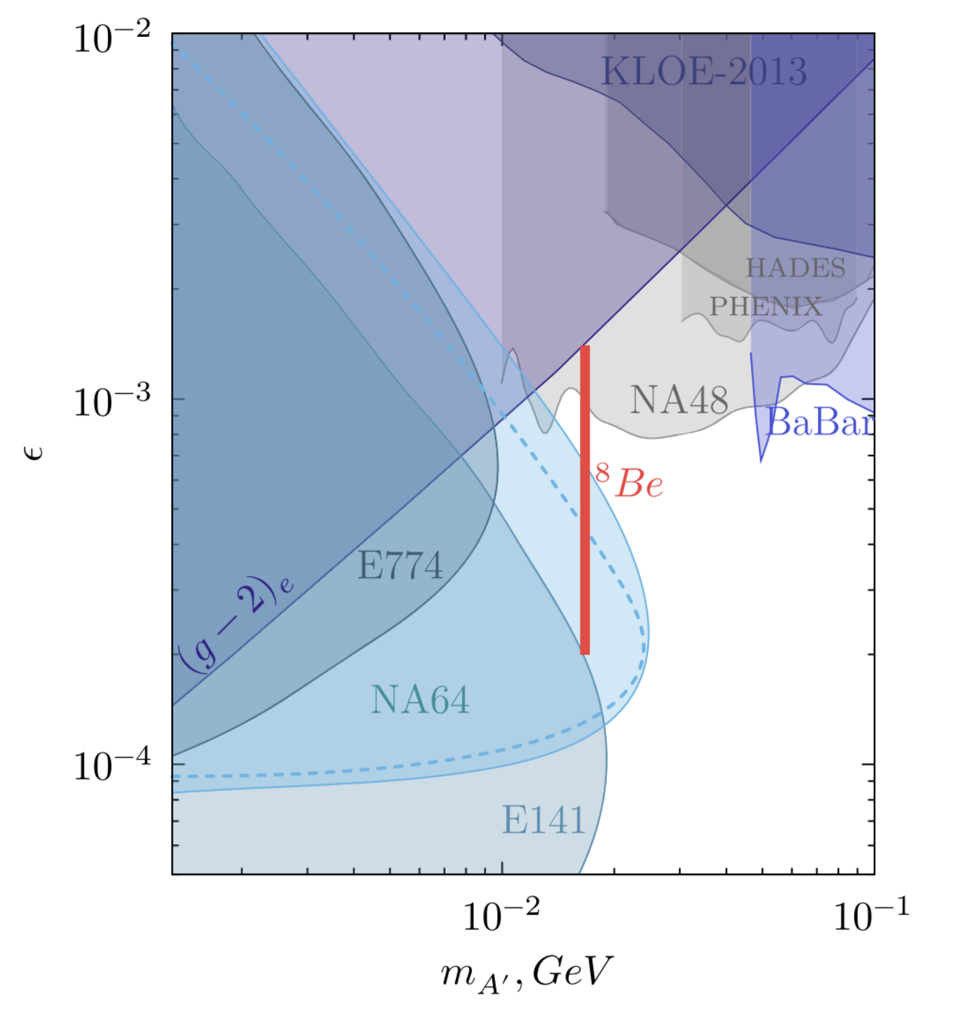
Our experiment is sensitive to these

# Exclusion Landscape Status

- NA64 is the most recent experiment to exclude more phase space
- ϵ is the the strength of the coupling to standard model matter relative to photon coupling
  - In the “protophobic” case, this is the coupling to electrons
- The red band is the phase space that is consistent with the Be8/X17 anomaly
- Note that in the protophobic hypothesis case, the NA48 exclusion region is not applicable
- Unexcluded region is ϵ > 6.8e-4 ($\epsilon^2$ > 4.6e-7)

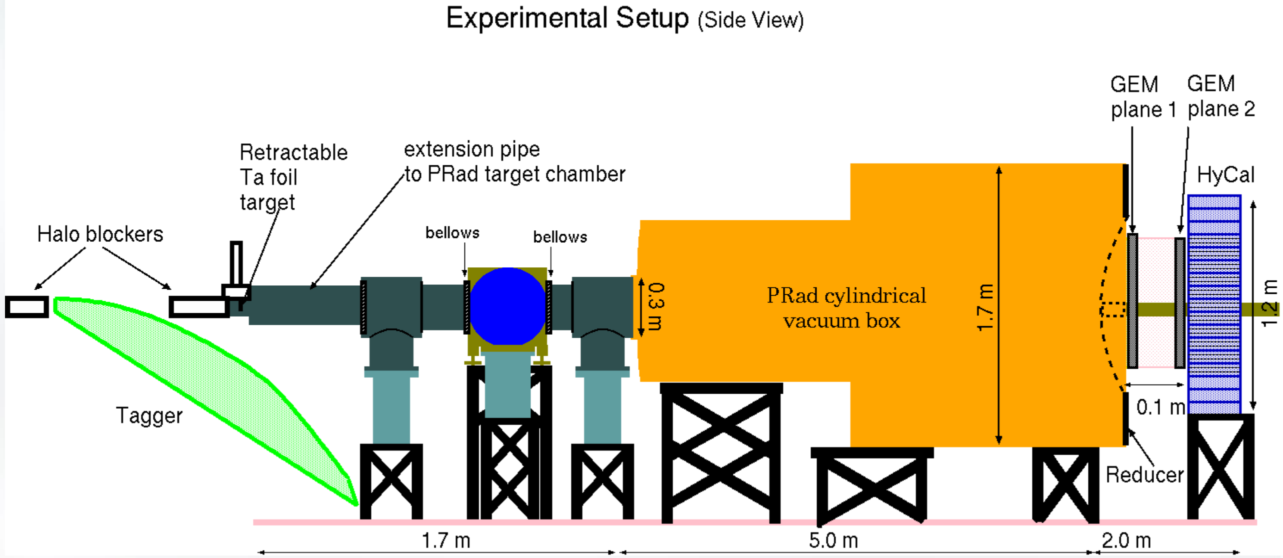
Figure from: Banerjee *et al*. *Phys.Rev.D* 101 (2020)



# The JLab X17 Experiment

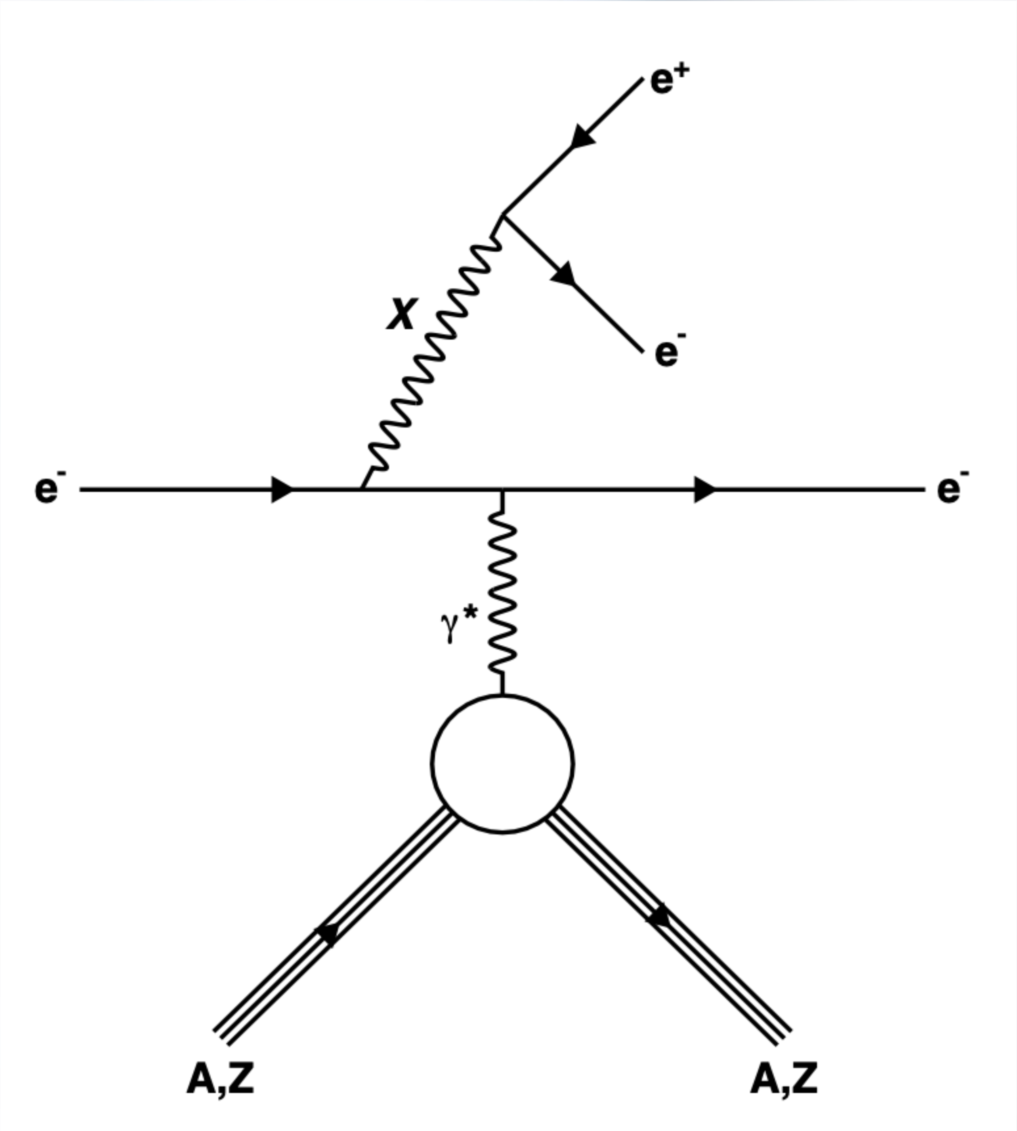
# Experimental Setup

- We will use the existing PRad spectrometer with a Tantalum foil mounted on the harp 7.5m upstream of the calorimeter
- Two new GEM planes separated by 10cm will provide tracking
- With the exception of the helium bag between the GEMs and the thin window on the vacuum box, the path from target to calorimeter is in a vacuum to minimize rescattering



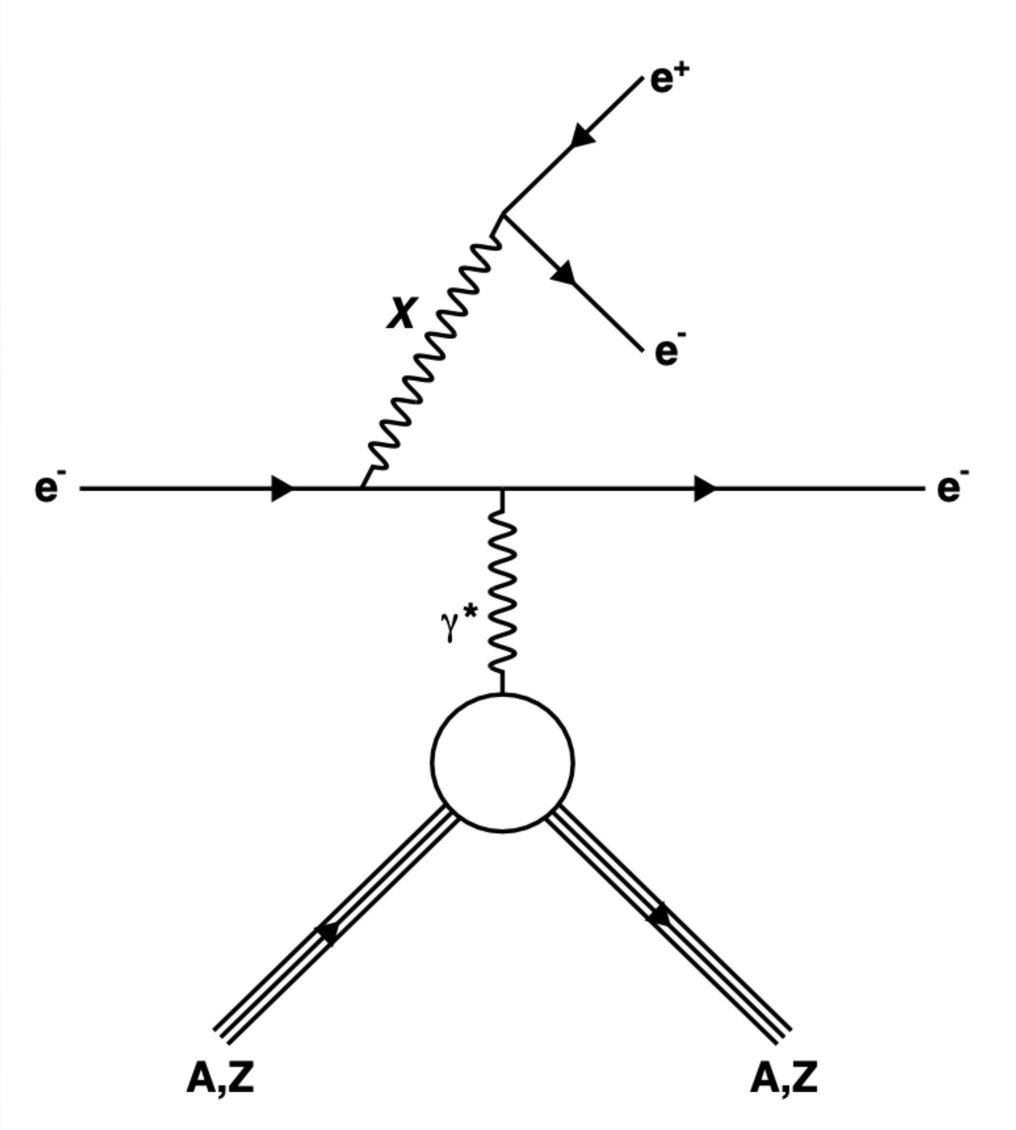
# Kinematics of the signal

- Uses a high-Z target as a “photon source” for Bremsstrahlung like production
- The target itself need not couple to the signal, bypassing any protophobic restrictions
- Cross section peaks at very forward production angles and momentum fractions
- We will use a very forward spectrometer without a magnetic field
    - More background
    - More phase space
- Very careful studies have suggested that the tradeoff works in our favor



# Planned Measurement

- We plan a bump hunt search
- This looks for an enhancement over background in the invariant mass spectrum of the final state
- Complimentary to displaced vertex searches like NA64
  - Displaced vertex searches place limits from small couplings up
  - Bump hunt searches place limits from large couplings down
- Our measurement is unique in that we will detect a 3-lepton final state, two decay products and the scattered beam
  - Reduces possible background processes through exclusivity cuts
  - Less phase space and added combinatoric background



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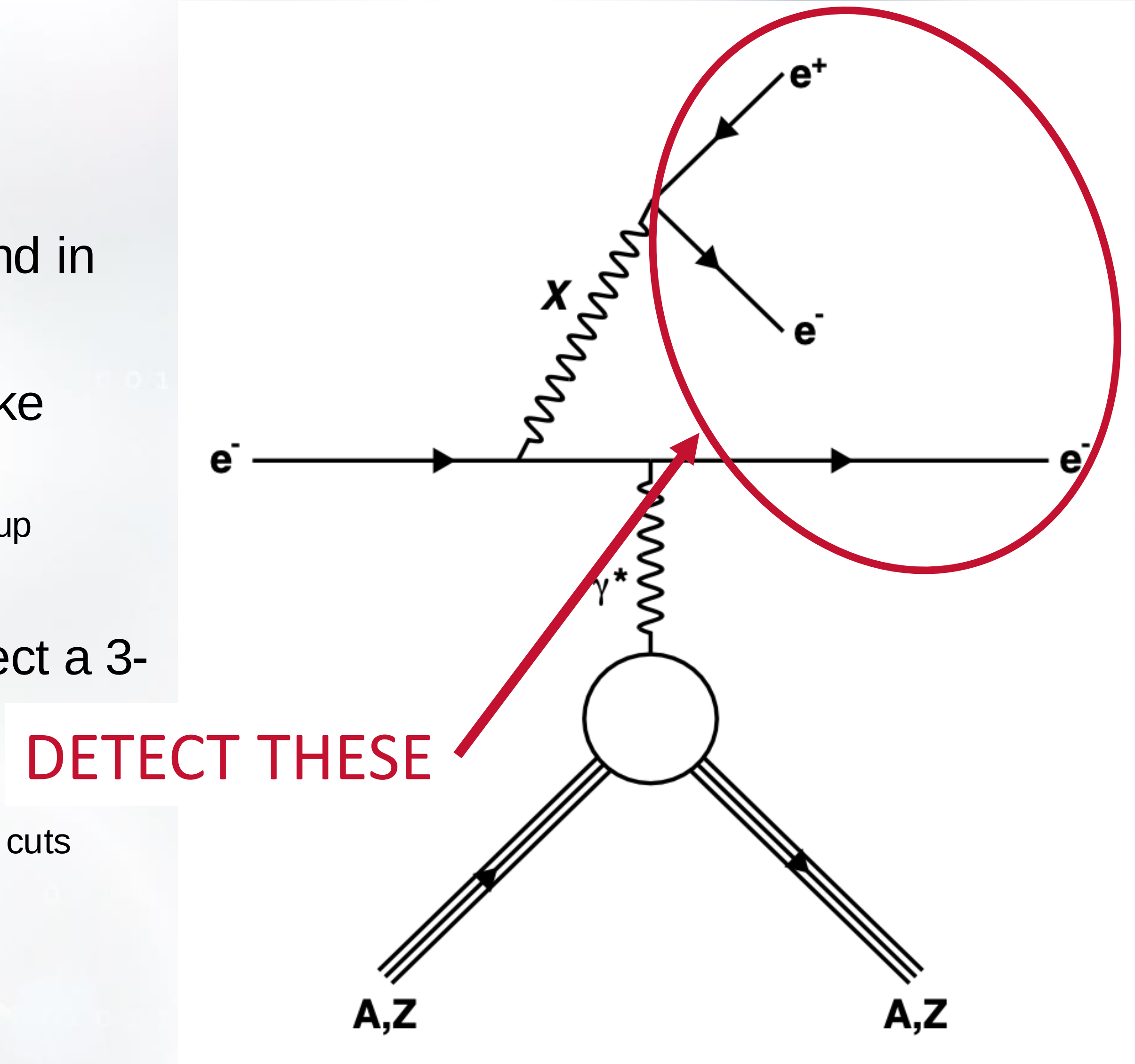
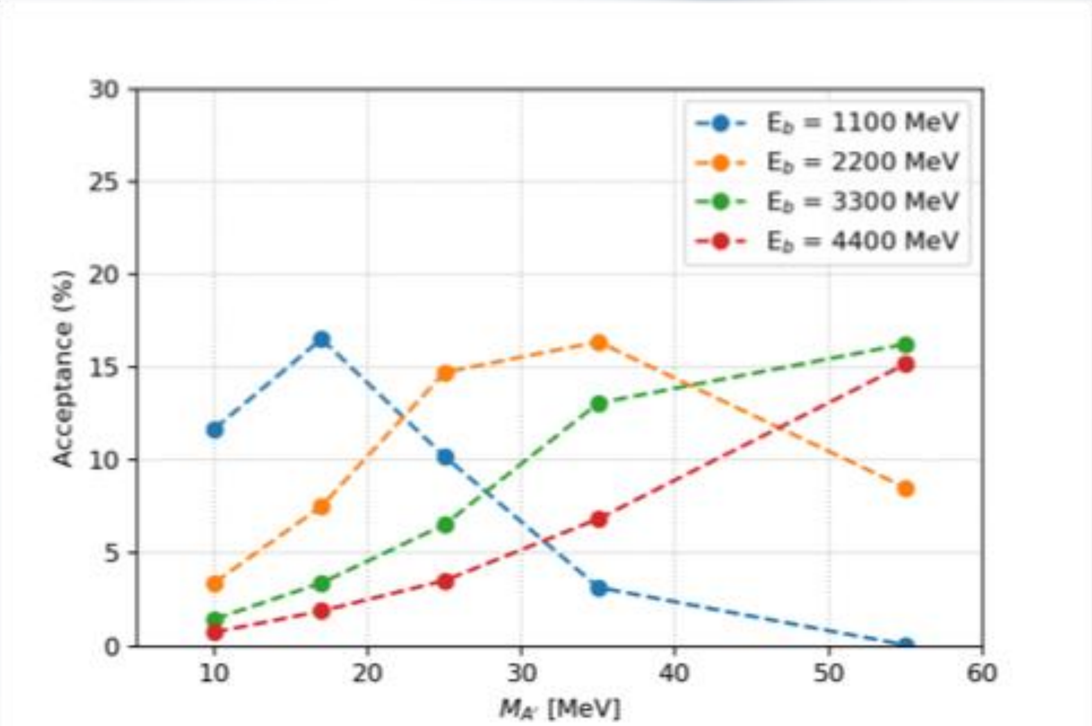


# Acceptance Studies

- Resolving the X17 Anomaly is the primary goal of the experiment
- However, our experiment is also sensitive to other masses with unexcluded phase space
- We have studied our acceptance for a mass range of 3-60 MeV to best understand the limits we will be able to set
- We have recently reassessed the acceptance of the experiment for different beam energies
  - Our original proposal called for a 3.3 GeV beam
  - However, that is unlikely to be available in the near future so we have recently assessed if we can achieve our goals with more standard CEBAF beam energies



Figures from: T. Beranek and M. Vanderhaeghen. *Phys.Rev.D* 89 (2014)

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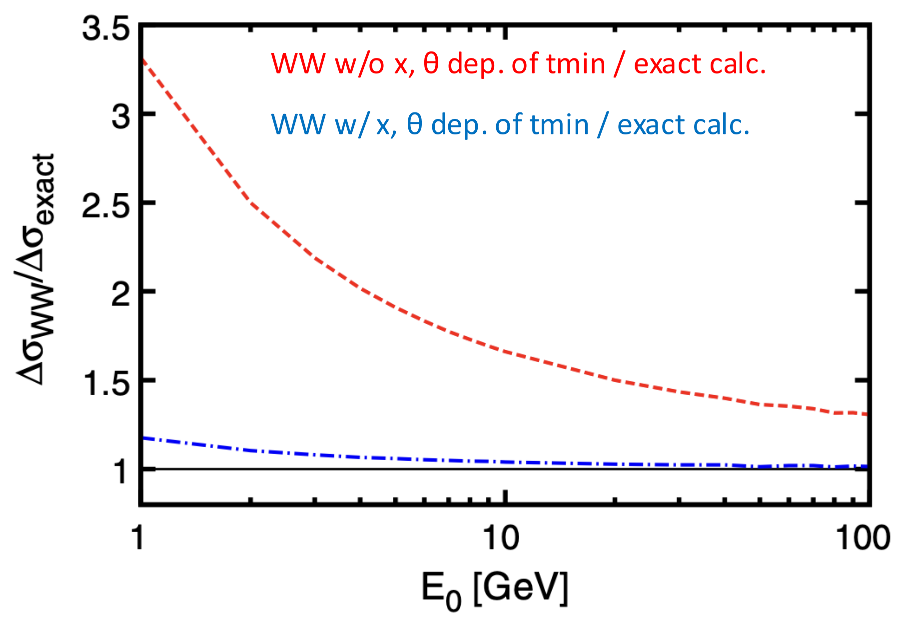
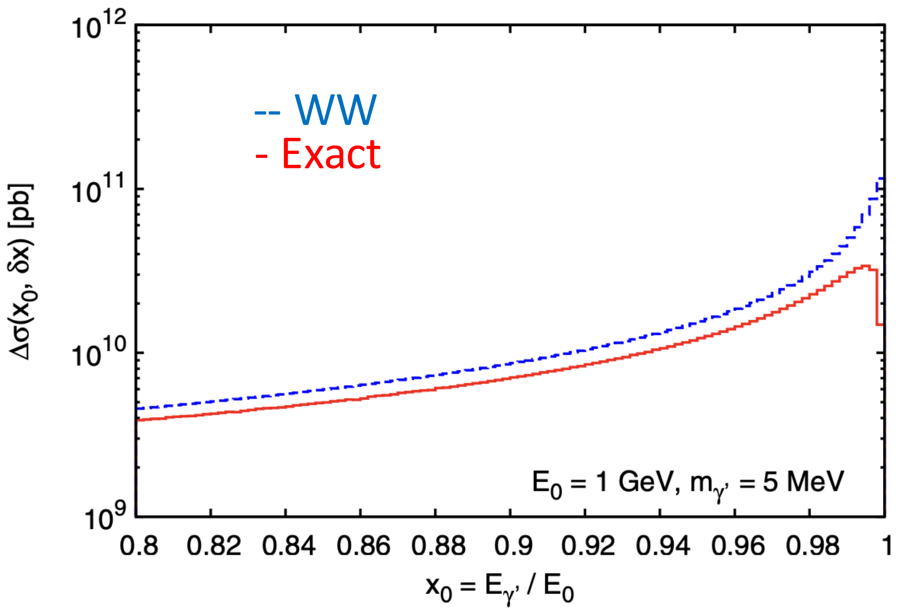
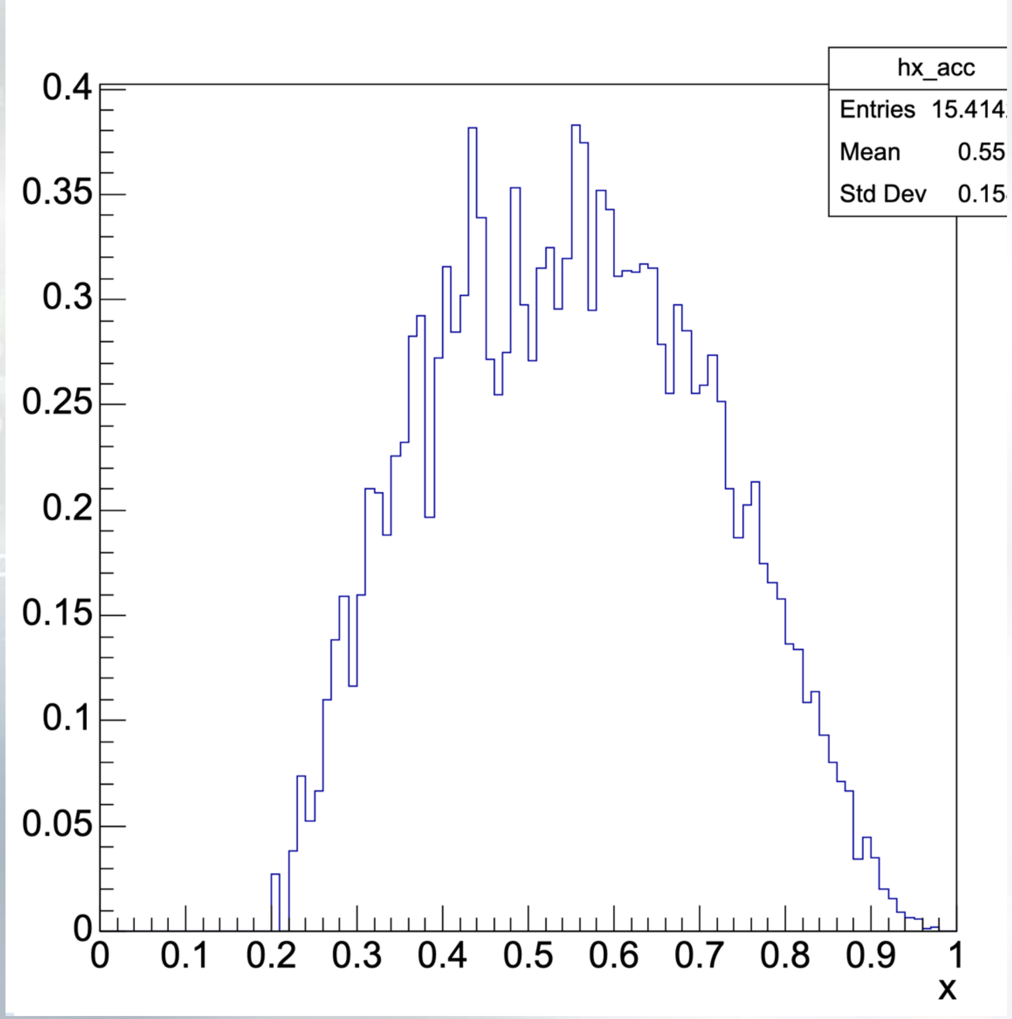
# A Brief Aside – A` Generators Lessons

- While performing these acceptance studies, we observed some, now explainable, discrepancies between independent checks
- Independent tests used three different generators
  - Weizsacker-Williams (WW) approximation
  - Weizsacker-Williams approximation with kinematically determined t_min
  - MadGraph5
- All three gave dramatically different results
  - We have learned that this is known behavior
- Our geometric acceptance cuts off where the Weizsacker-Williams approximation begins to break down, magnifying these differences
- MadGraph5 calculates the exact matrix

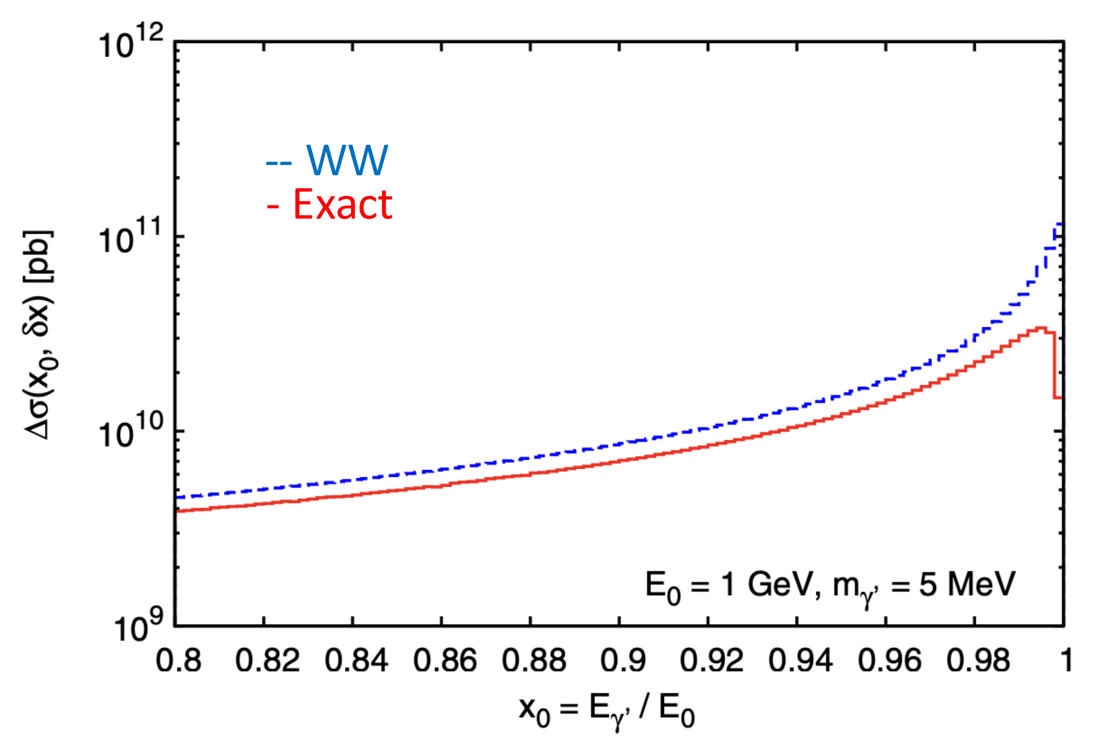


# Acceptance Studies and Generators

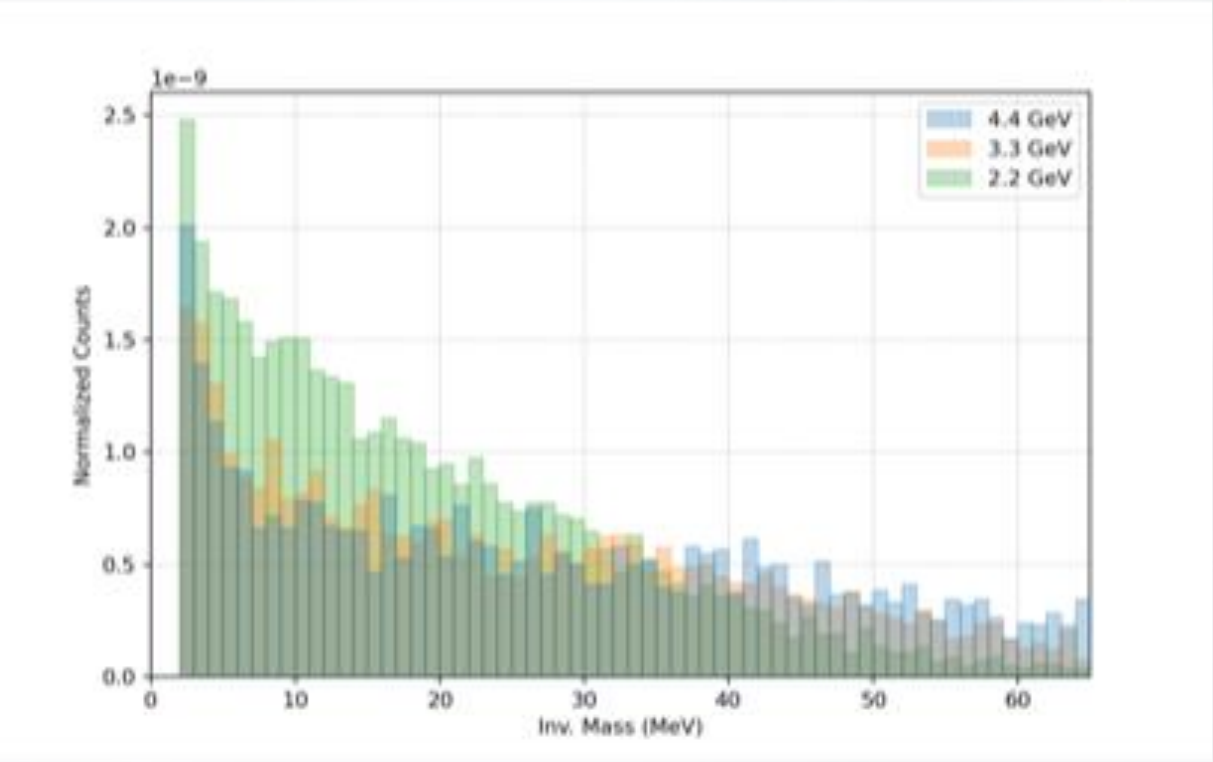



Our acceptance falls at high energy fractions
Exact calculations have a much broader peak at high energy fractions bringing more events into our acceptance



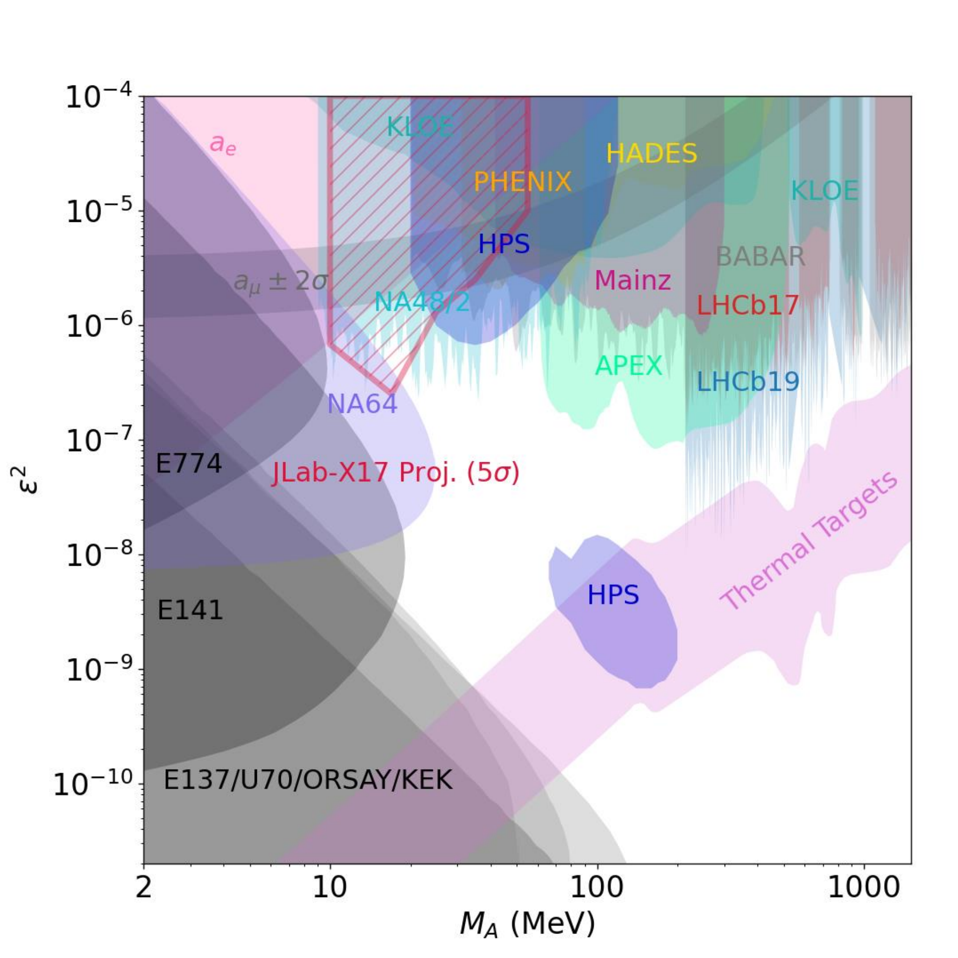
# Background Studies

- Our experiment has four dominant backgrounds
  - Radiative (Bremsstrahlung) pair production
  - Bethe-Heitler pair production
  - Wide-angle Bremsstrahlung
  - Interference of these
- We have studied our background rates using samples from the MadGraph5 generator
- This generator has been benchmarked against already recorded HPS data and shown to accurately reproduce these distributions
- As our detector does not have a magnet, we also have a background from combinatorics of the 3-lepton final state of the above backgrounds *and* any possible signal



# Anticipated Reach

- We will use ~40 days of beam time divided between 2.2 GeV and 4.4 GeV to do our search, with the bulk of the time at 2.2 GeV
  - Exact distribution is still being discussed
- All of our studies have shown that 2.2 GeV has both larger acceptance and the acceptance is at kinematics with a ~3x better signal to background ratio
- The 4.4 GeV will be used as a systematic check that we do not have any kinematic mimicking of a signal “bump”
- On the right are the anticipated *5σ* exclusion limits with 25 days of beam at 2.2 GeV



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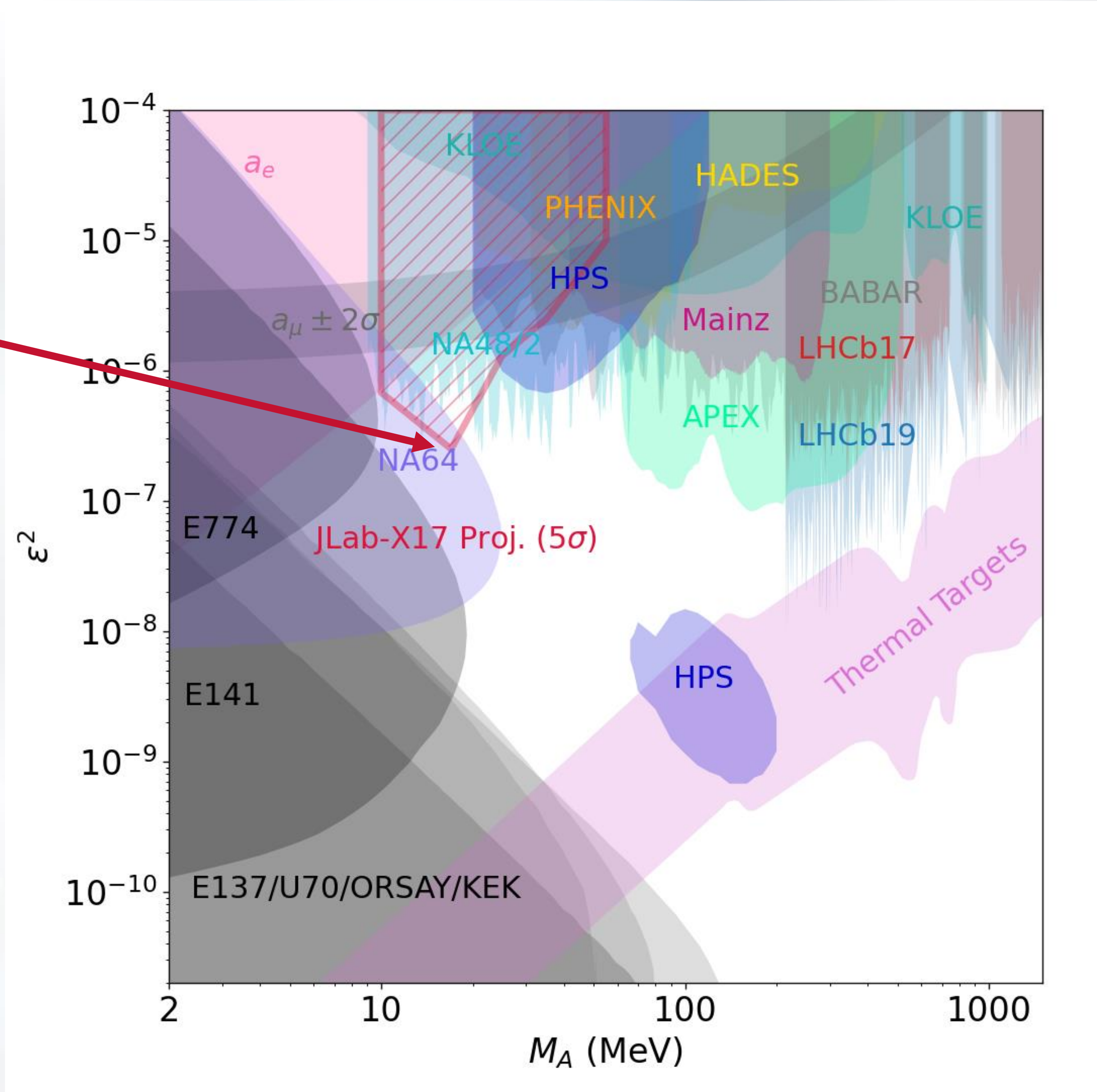
*Sure looks like it!*



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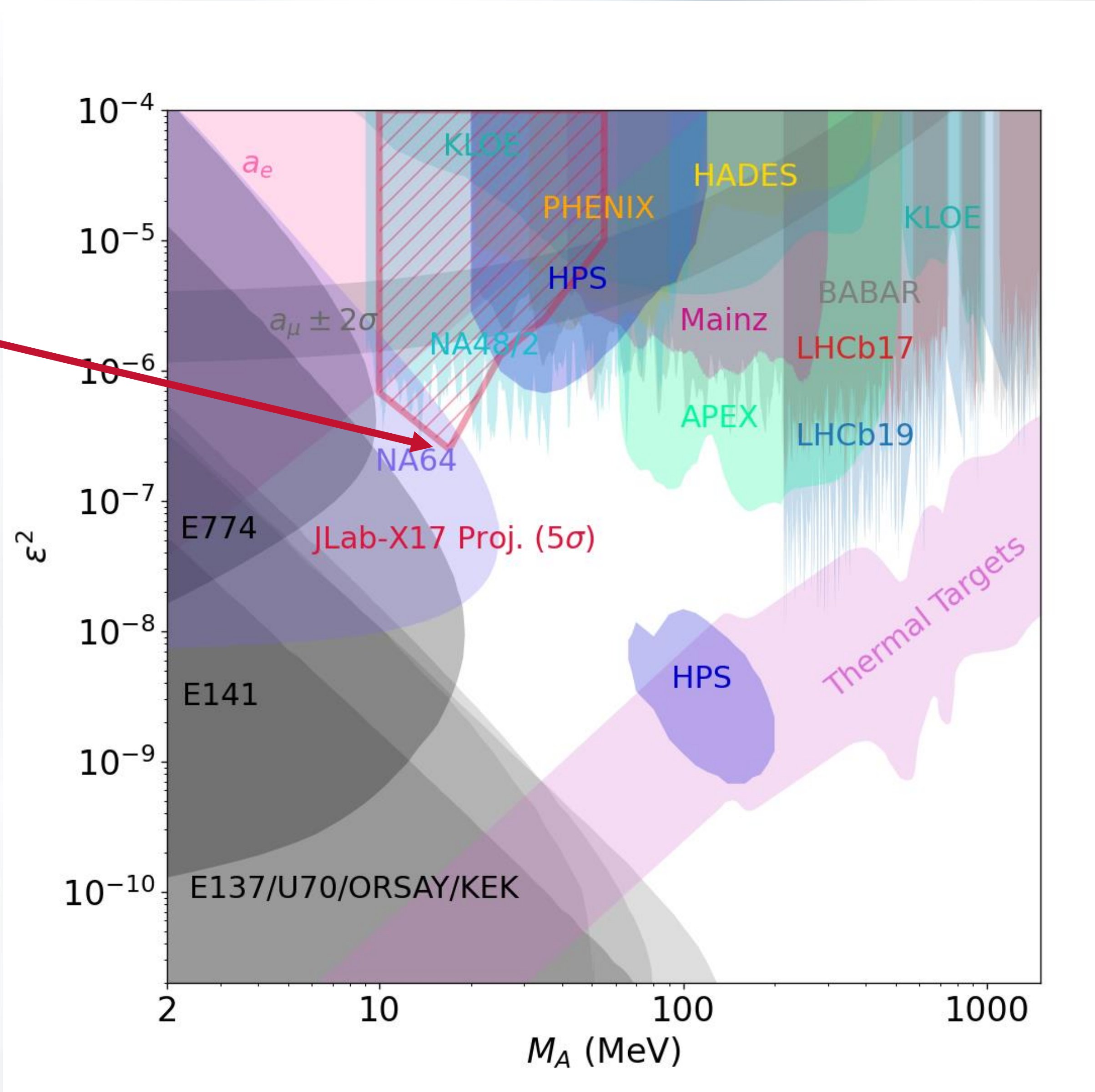
These simulations assume an 85% detector efficiency, which is worse than expected

Our plotted exclusion limit is for 5σ, other limits are set at 2.3σ



# What’s next and summary

- Finalize our signal and background studies
  - We believe that these are accurate, but we have some final checks left to ensure accuracy
- Finalize distribution of beam time between 2.2 GeV and 4.4 GeV
- Run the experiment!

- Using the PRad spectrometer, we will perform a hidden sector search
- We will detect the entire 3-lepton final state
- We can resolve fifth force explanations of the X17 anomaly

# QUESTIONS?