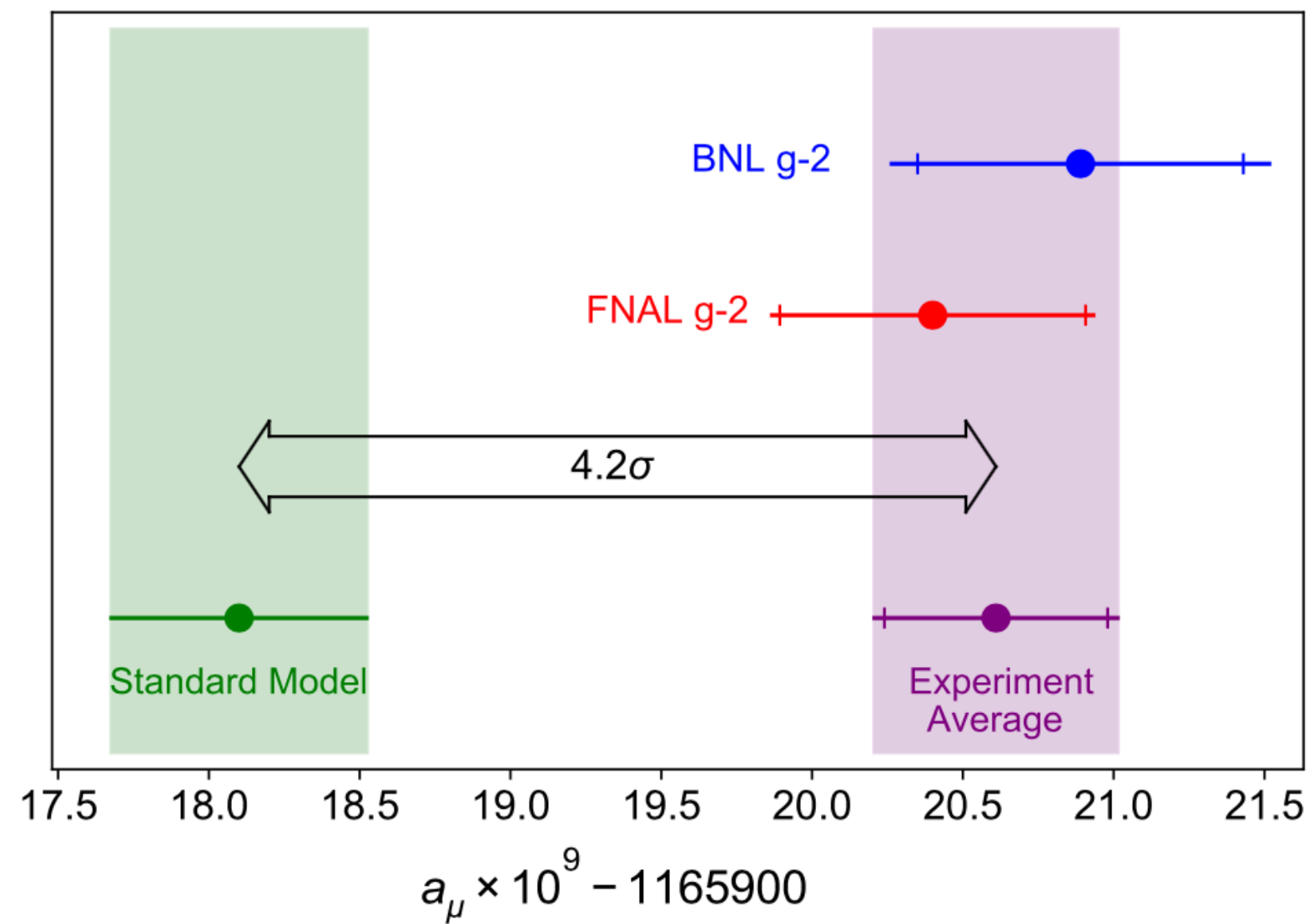


DARKLIGHT, Anomalies, and Other X17 Searches

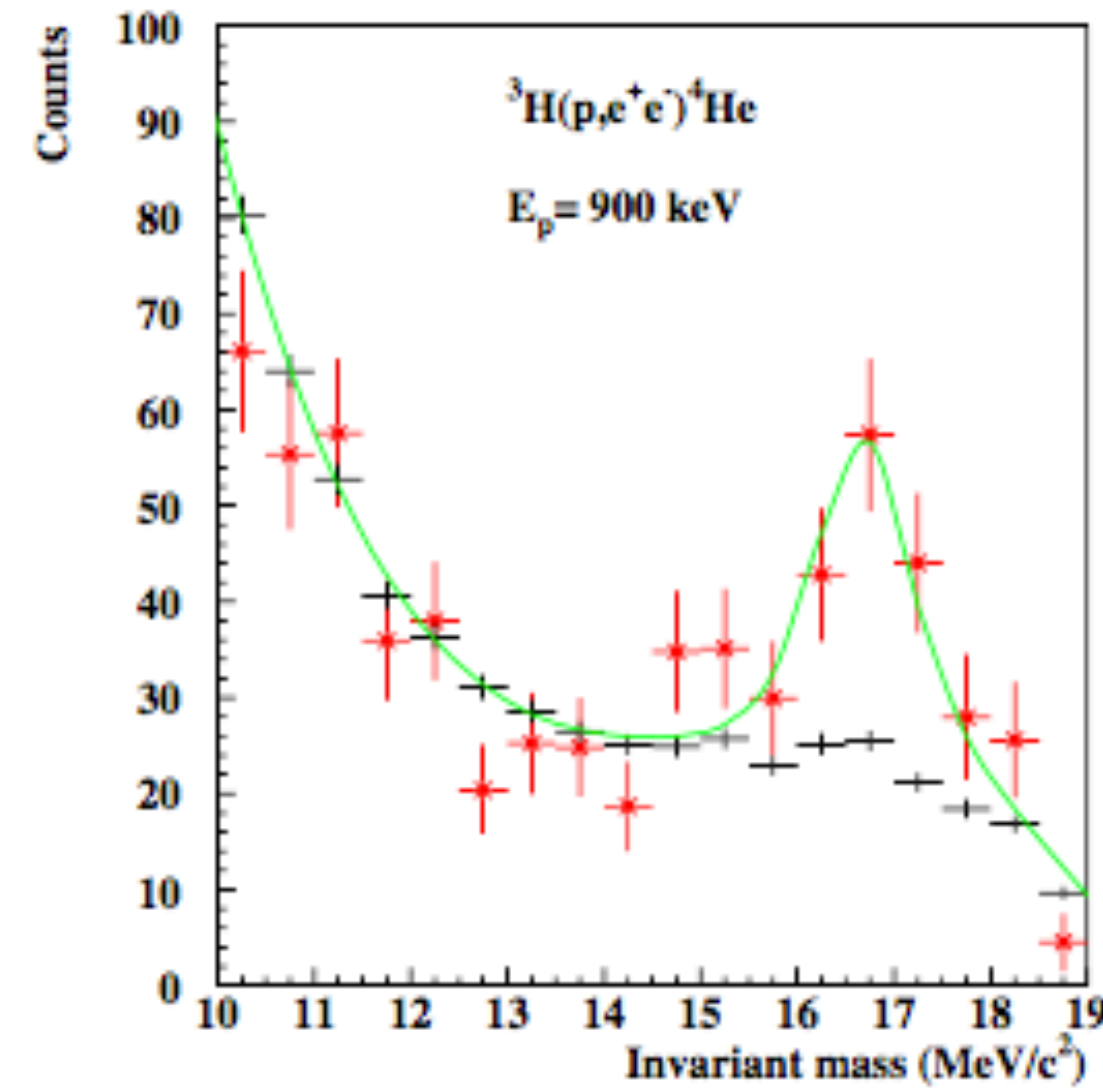
Ross Corliss

Physics Refresher

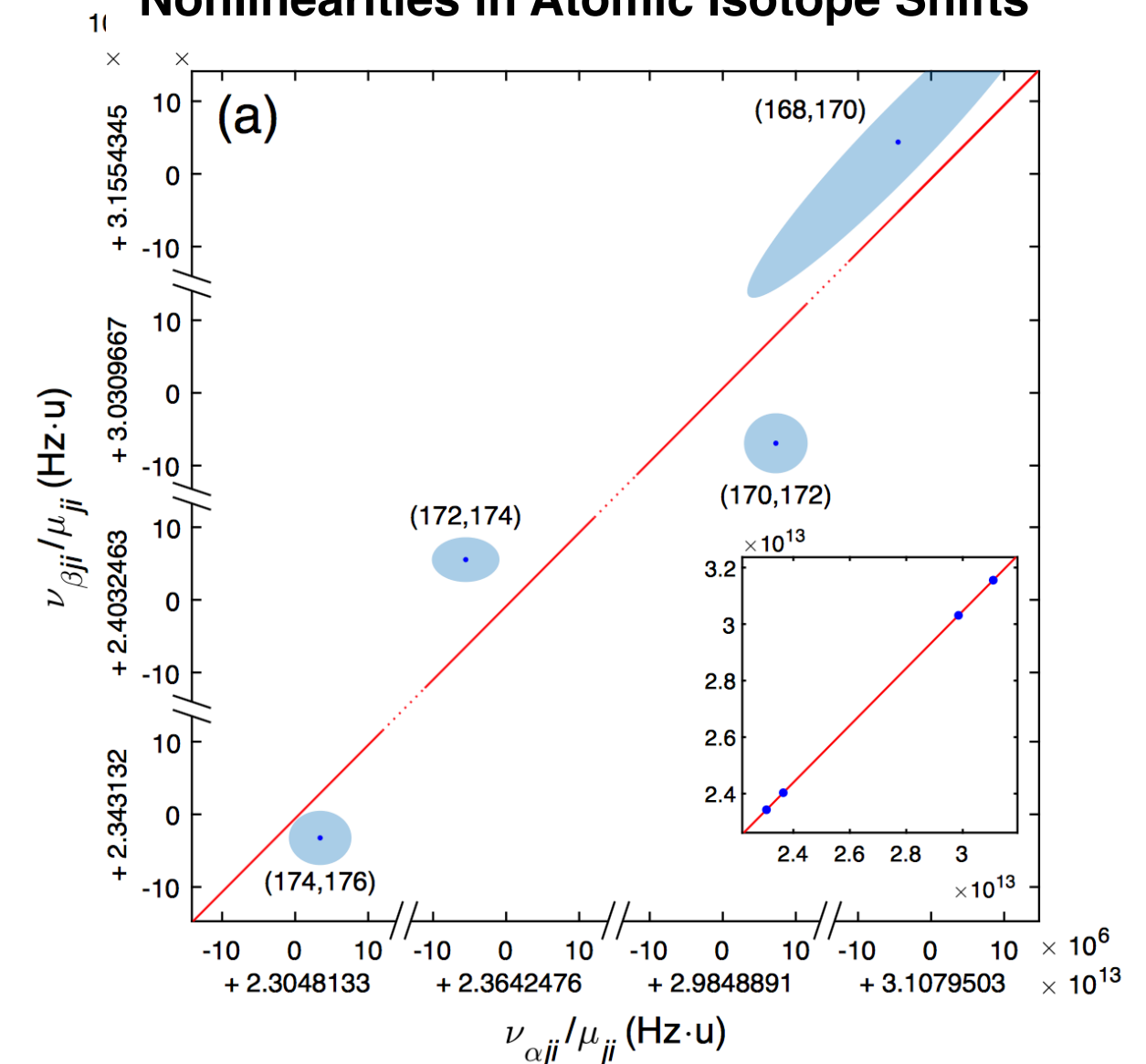
Muon g-2 Discrepancy



X17 in 4He and 8Be

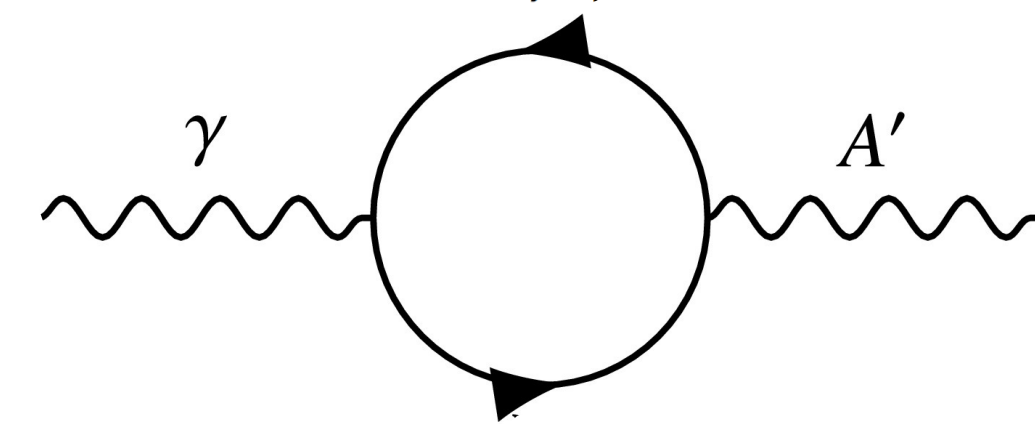


Nonlinearities in Atomic Isotope Shifts



- Anomalies could be resolved with a new interaction:
- Kinetic Mixing couples to SM electric charge

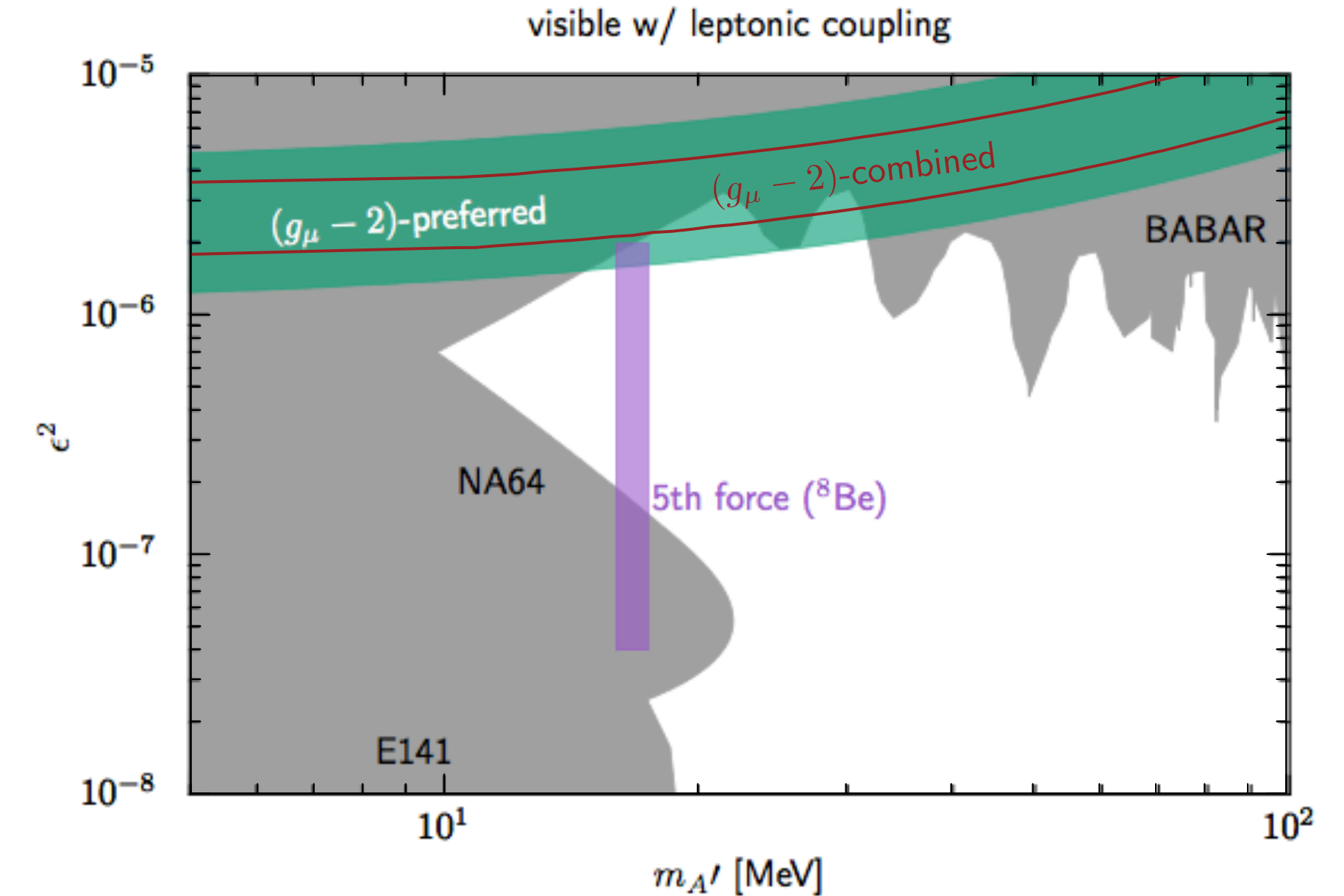
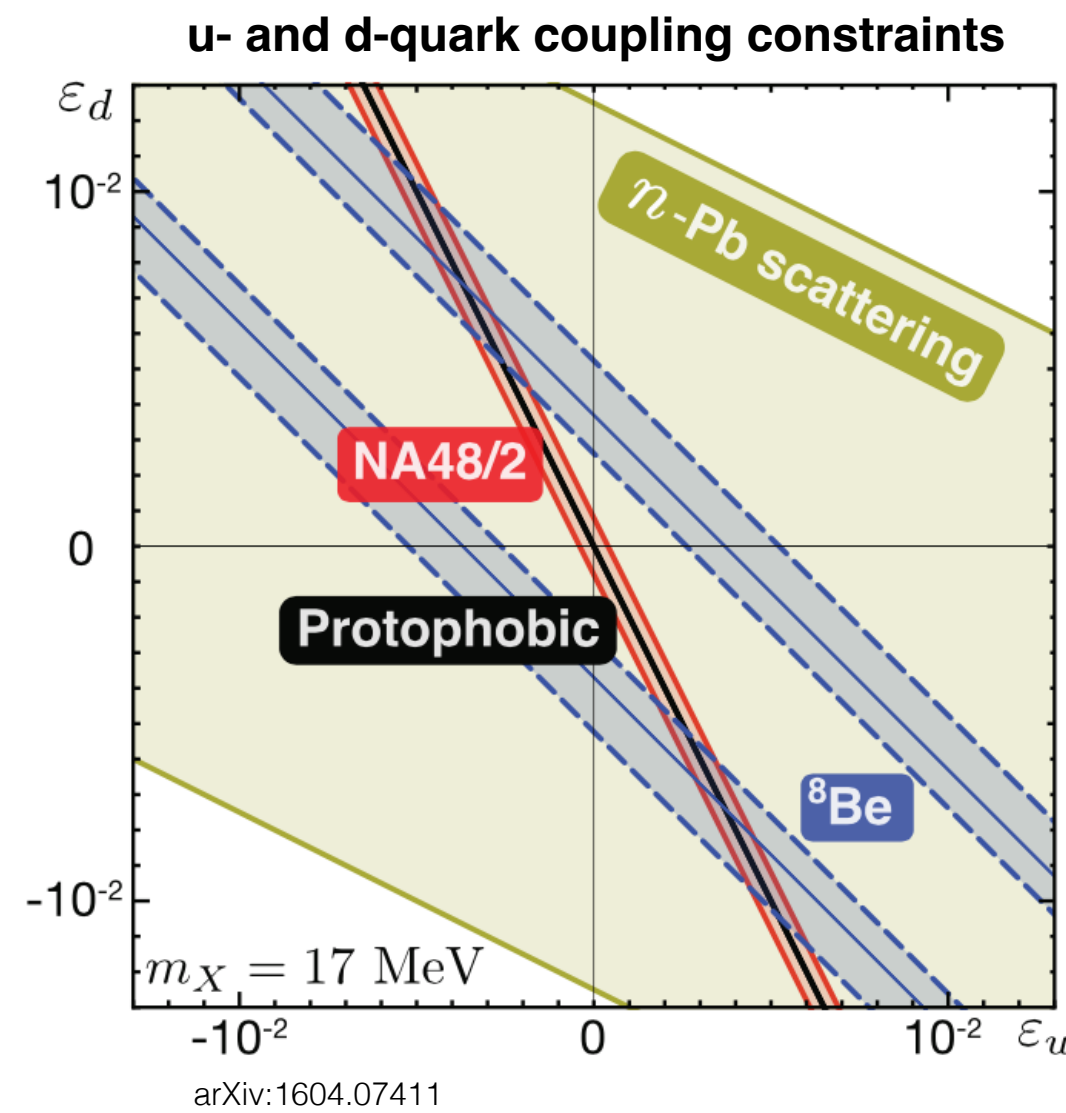
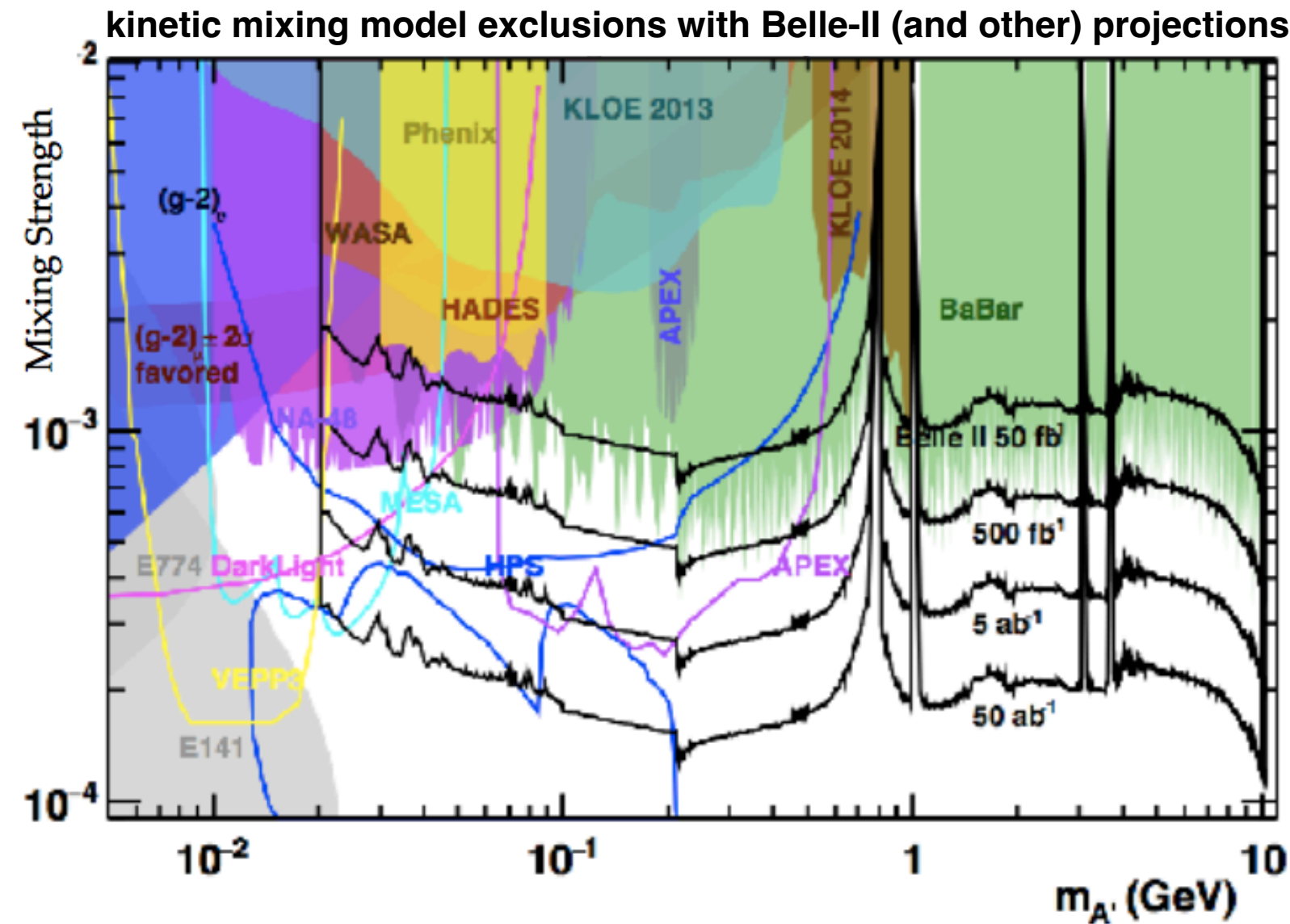
$$\frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu}$$



- but Generic new force could have flavor-dependent coupling:
- Parameterized by coupling (ϵ_f) and mass

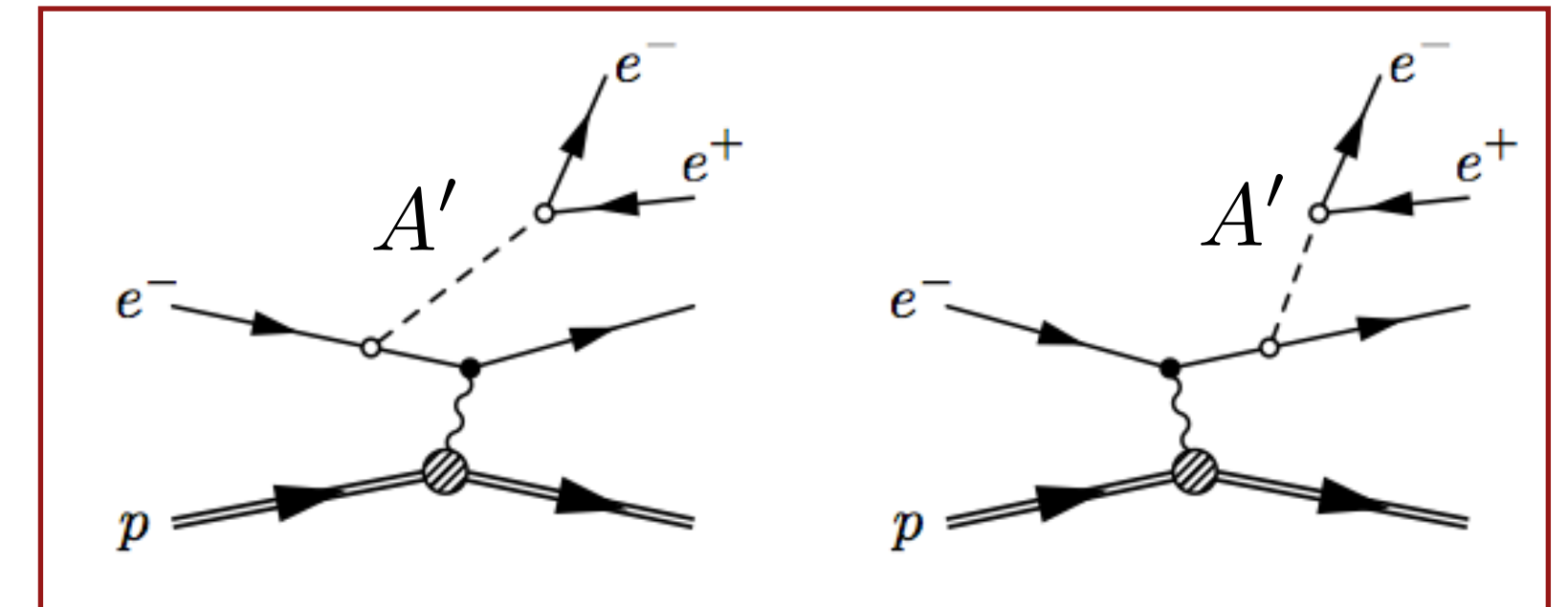
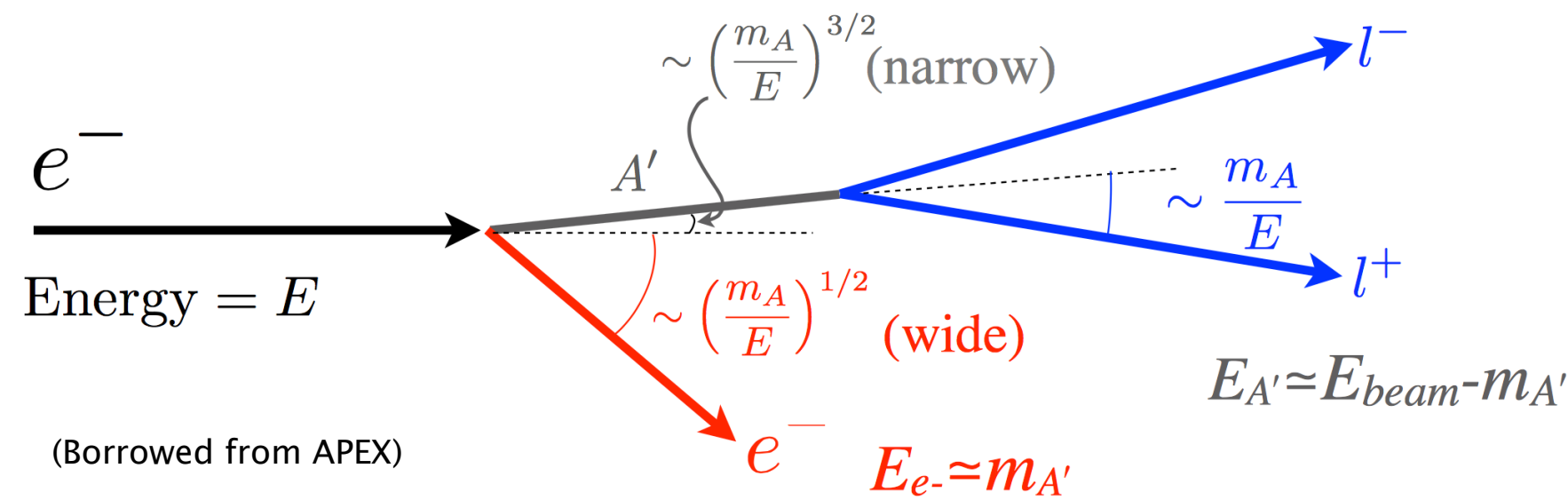
$$X^\mu (\sum_f e \epsilon_f \bar{f} \gamma_\mu f)$$

Direct Searches and Protophobia

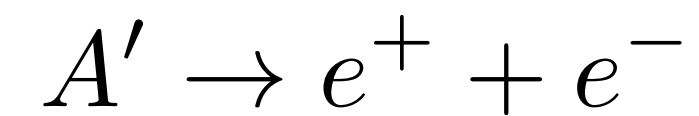


- Kinetic mixing disfavored by existing searches via hadronic production of A'
- Flavor-dependent couplings allows 'protophobic' solution
- **Purely leptonic production** key aspect of expanded search for this new particle
- X17 region can be reached with **low beam energy**

You Are Here



- Radiative production:

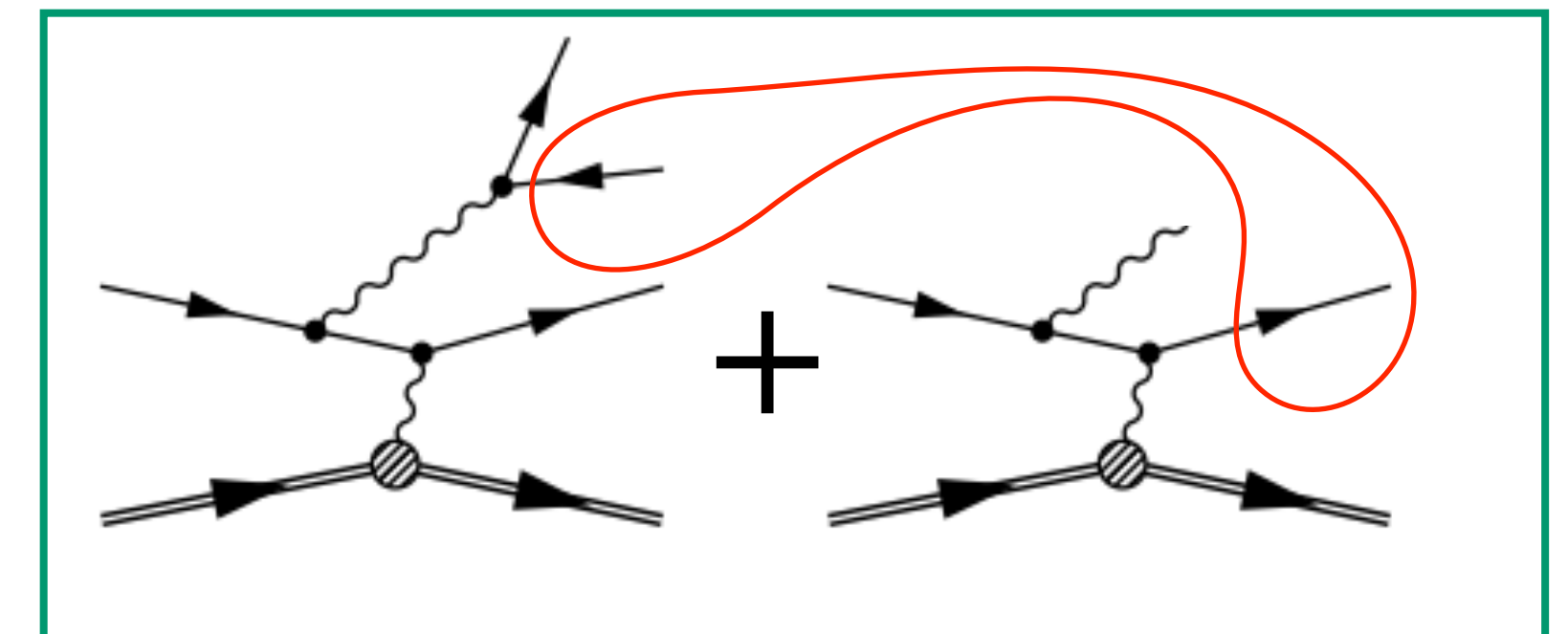
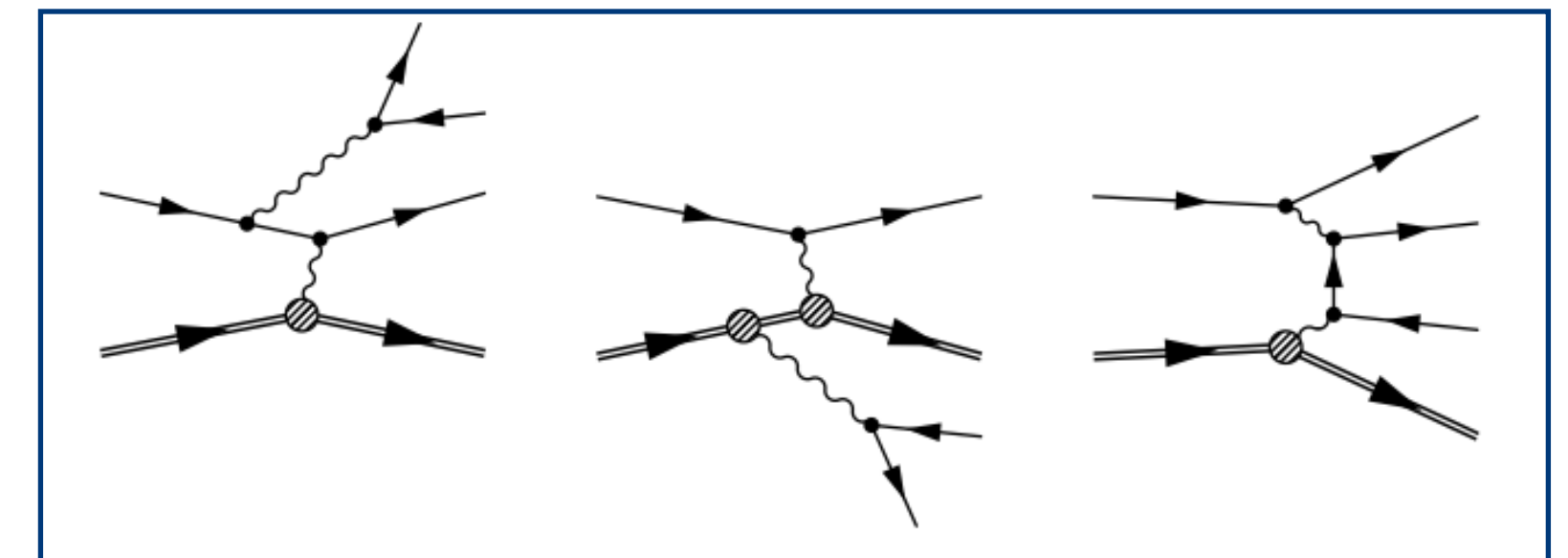


- Irreducible QED background similar, but no mass peak:

- $\text{FOM} \sim \frac{S}{\sqrt{B}}$

- Want to maximize integrated luminosity

- stop gaining when quadratic background dominates:



What's New in Anomalies

- X17 ^{12}C (<https://arxiv.org/abs/2209.10795>)
- King Plot SM combined analysis (<https://arxiv.org/abs/2111.01429>)
- g-2 combined result (<https://arxiv.org/abs/2107.02021>)

X17

- ATOMKI group sees anomaly in ^8Be , ^4He , *and now ^{12}C too*
- Persists in original 5-fold and new 6-fold geometry (but most detector angles are the same)
- *Very* incompatible with simple kinetic mixing model
 - would have been seen in pion decay etc

X17 in ^4He and ^8Be

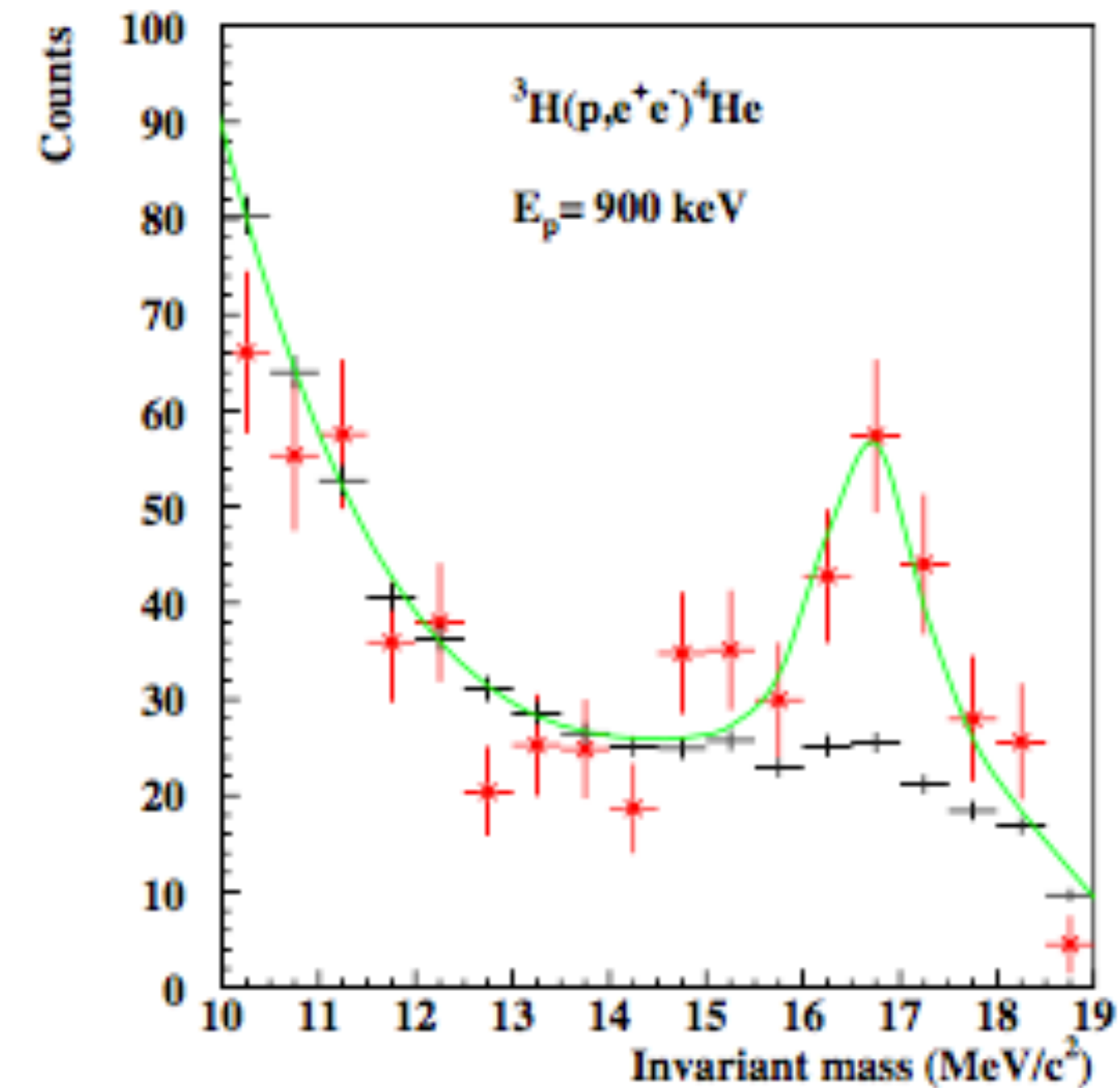
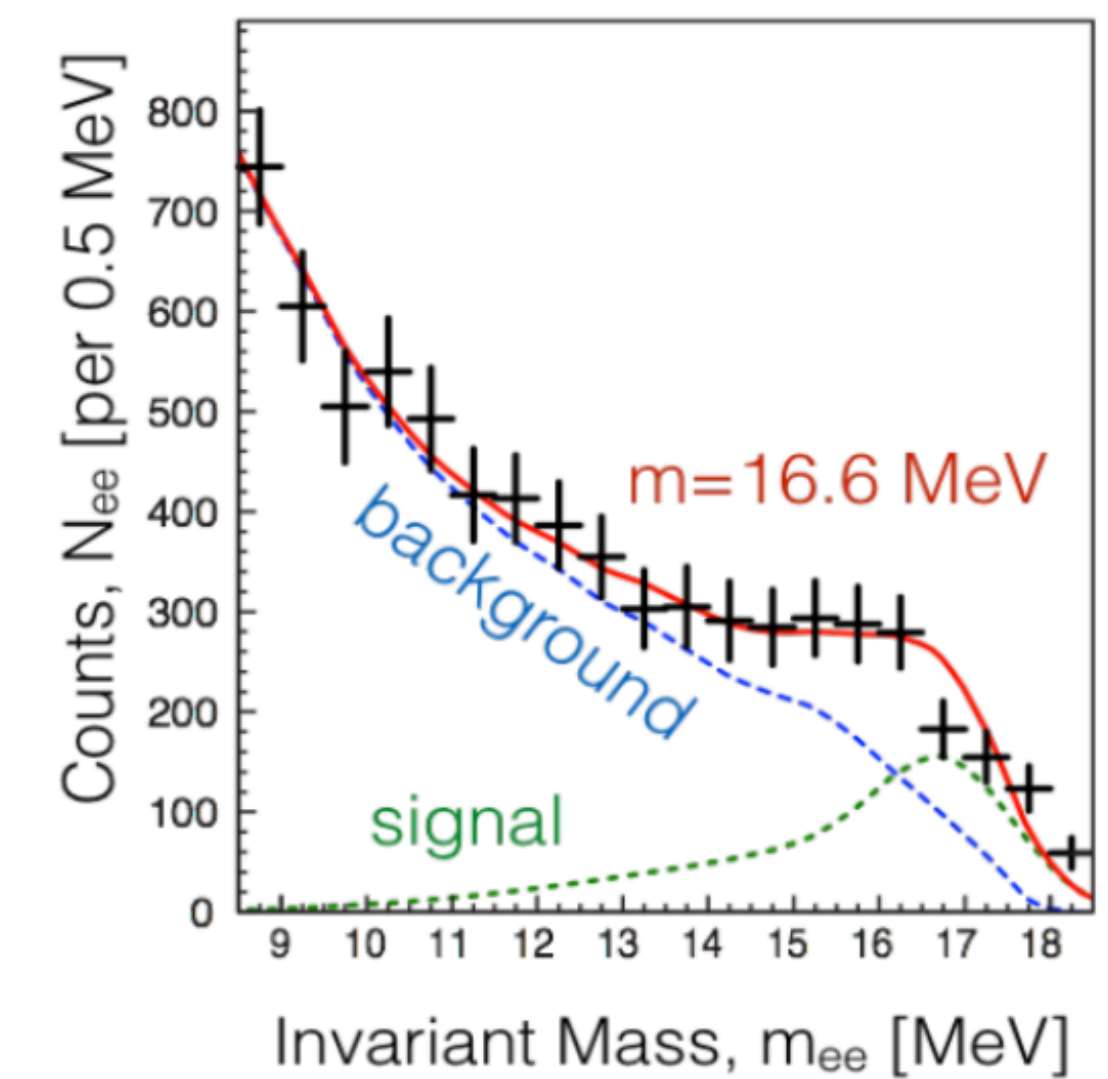
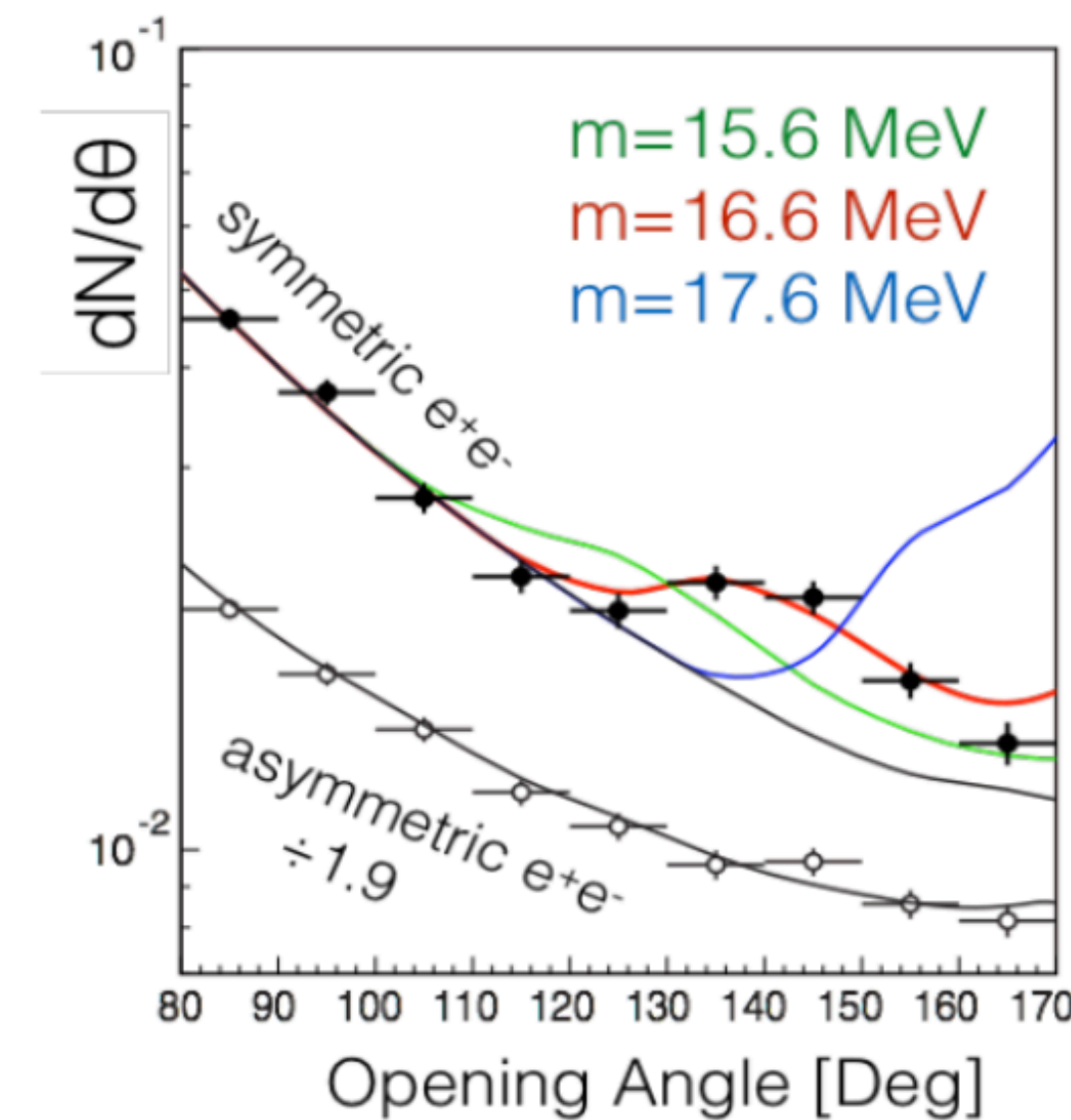
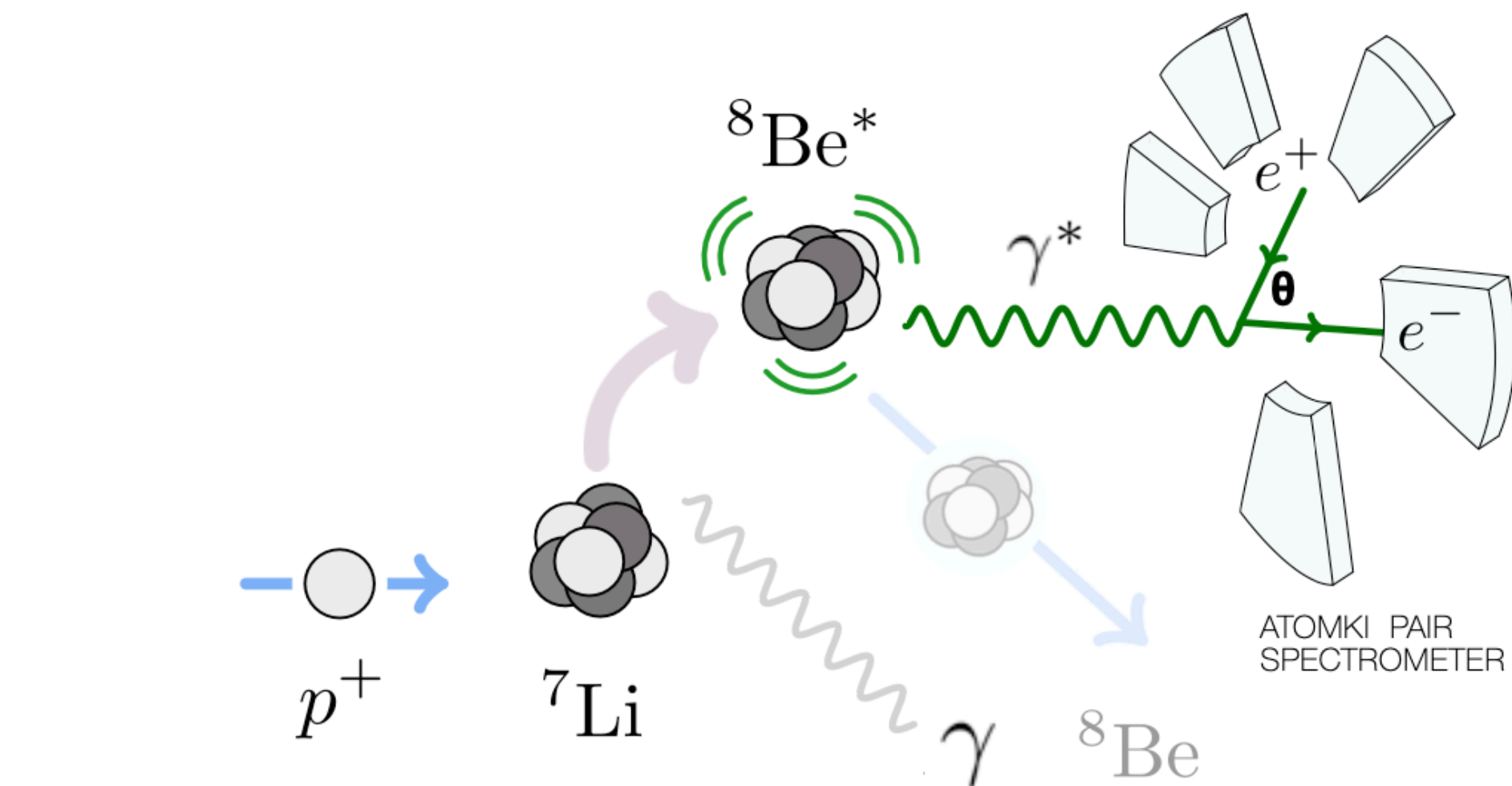


FIG. 3. Invariant mass distribution derived for the 20.49 MeV transition in ^4He .

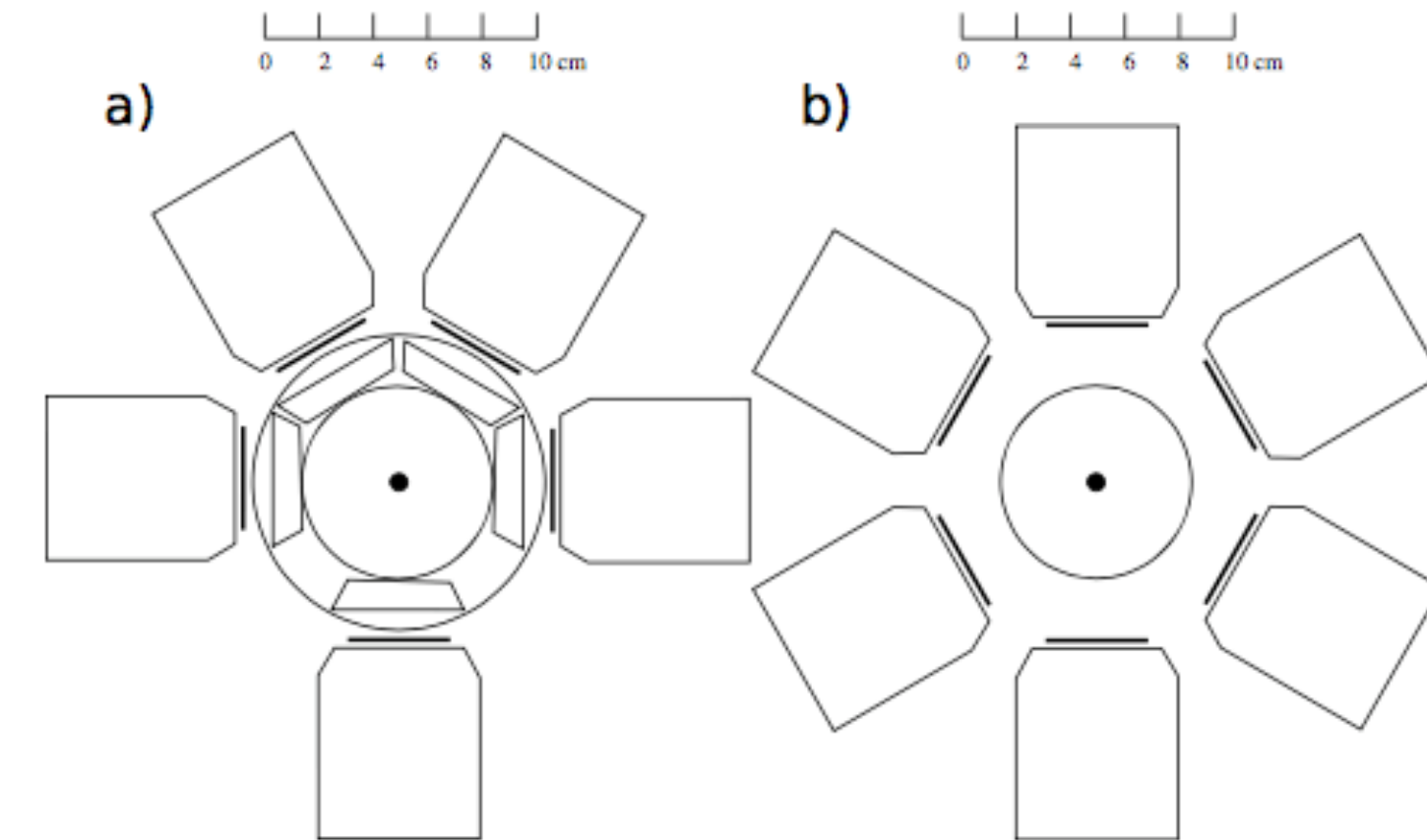
X17

- Very rarely, $p+Li$ produces very excited 8Be state
- Rarely, 8Be will de-excite through photon/ internal pair creation (IPC)
- Detect e^+e^- pairs, construct spectra, verify against nuclear model.
- ...and find an anomaly consistent with massive particle

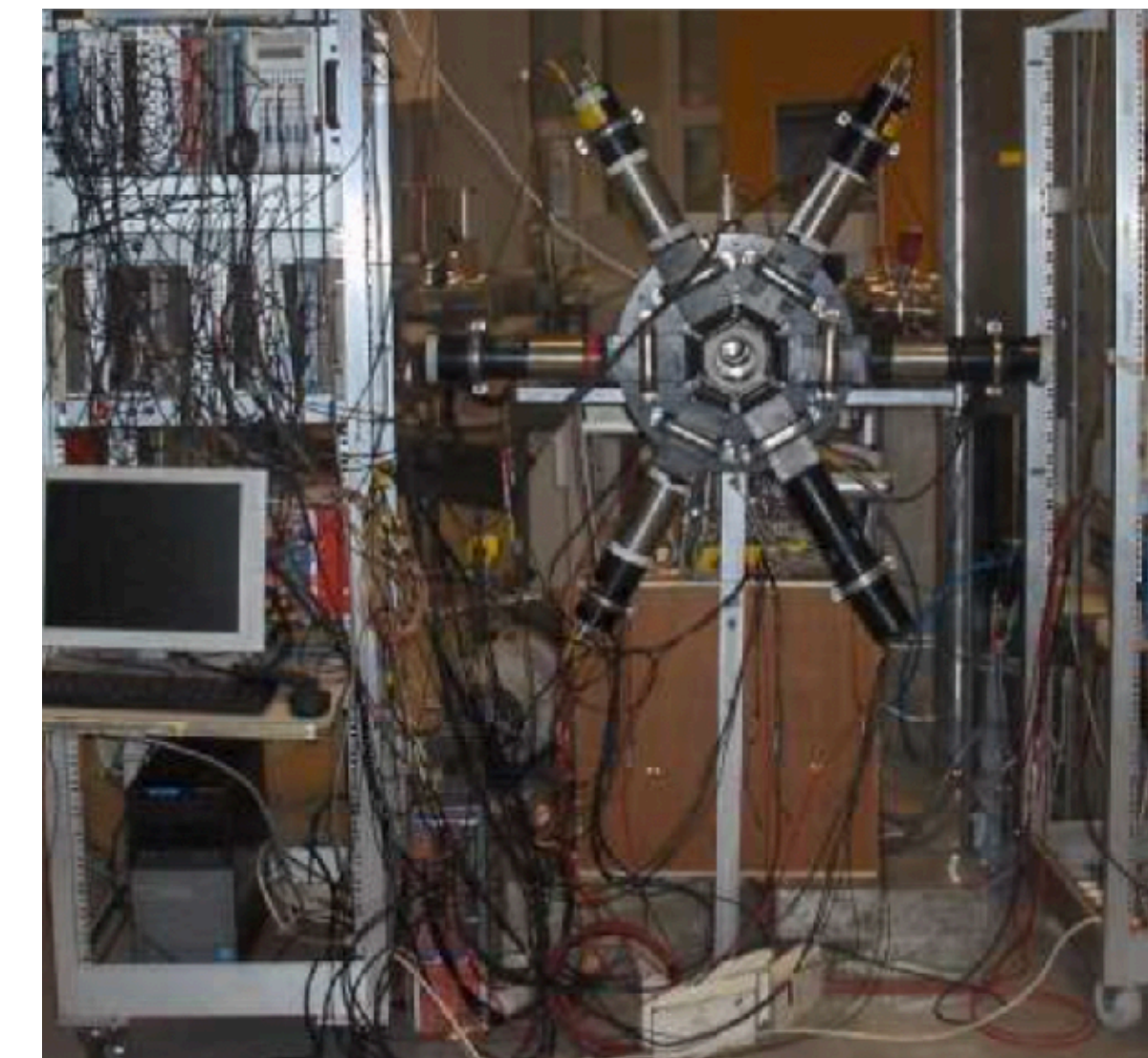
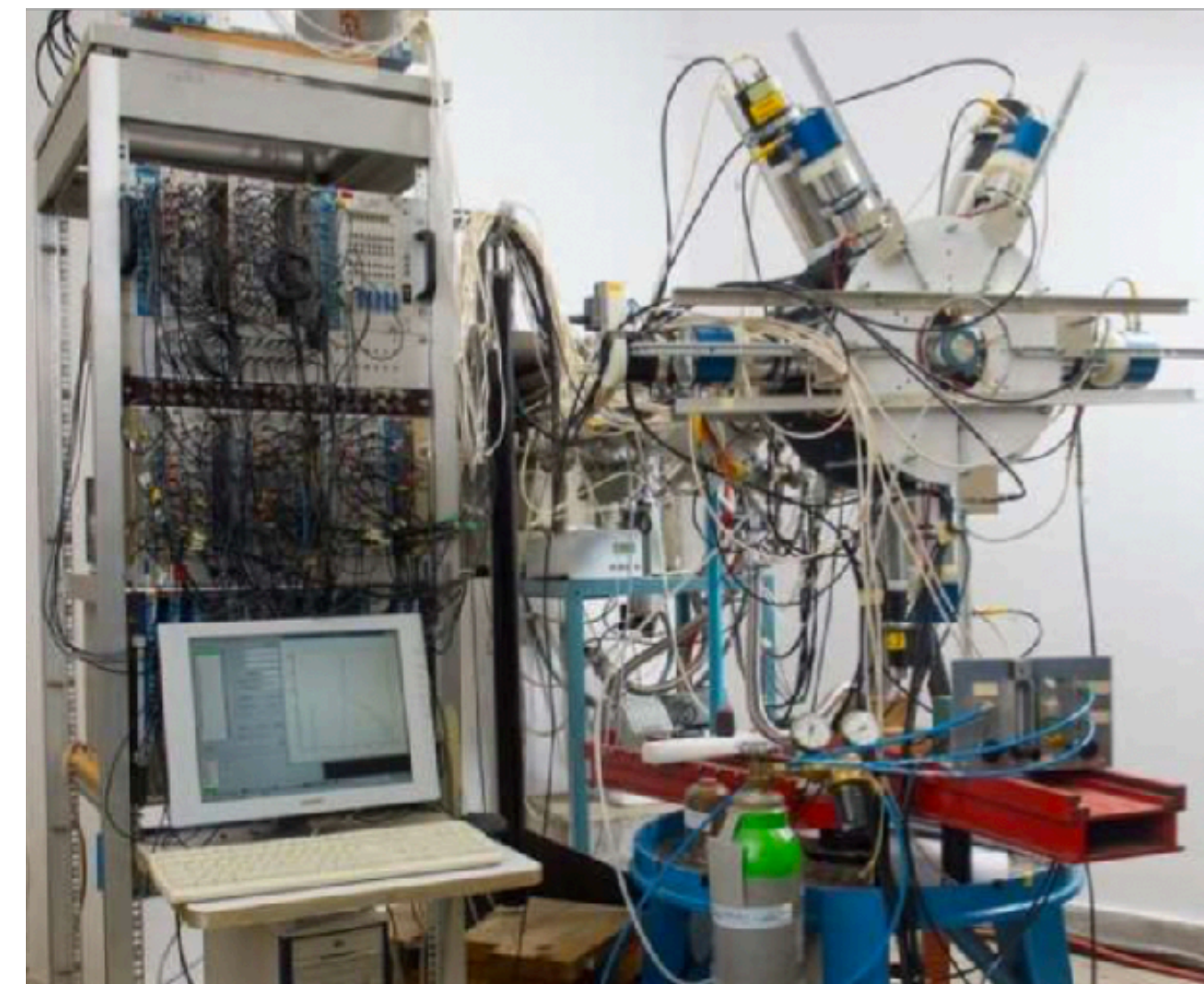


X17

- Seen in 5- and 6-fold detectors
- Seen in 3 different nuclei
- Could be nuclear effects, maybe intermediate state, interference, anomalous form factor... but no clear explanation yet.

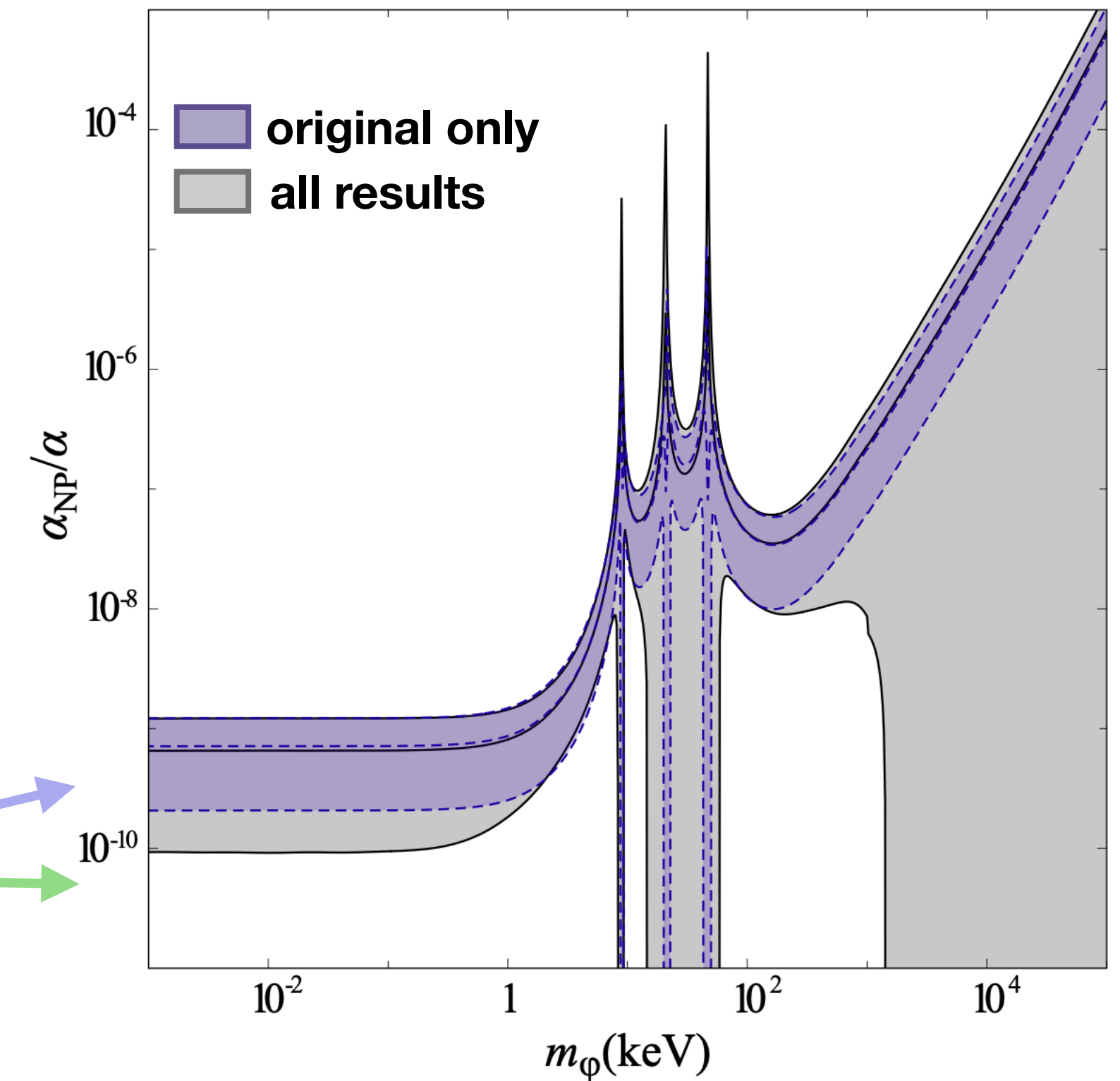
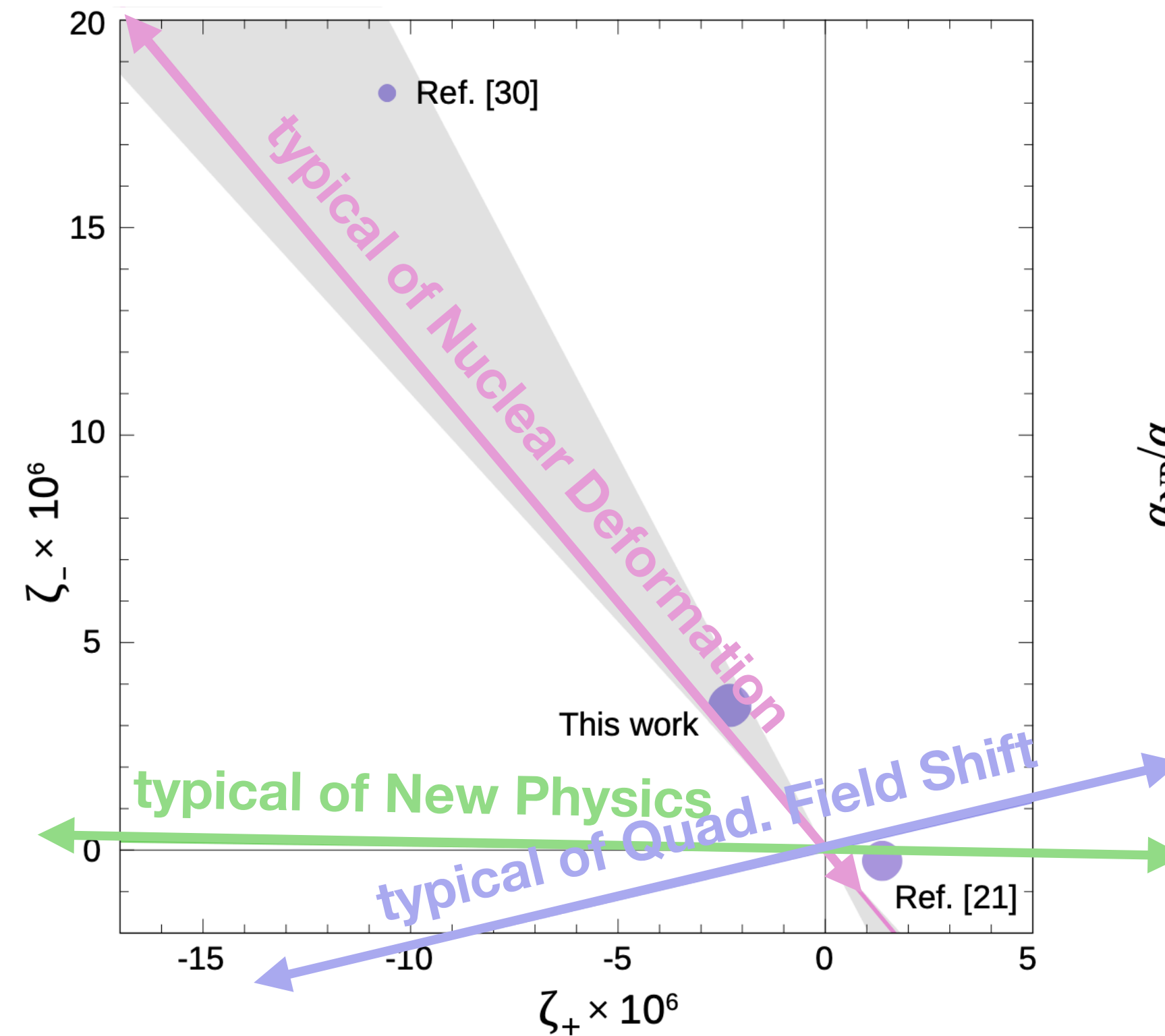


E_p (MeV)	B_x $\times 10^{-6}$	Mass (MeV/ c^2)	Confidence
1.50	1.1(6)	16.81(15)	3σ
1.70	3.3(7)	16.93(8)	7σ
1.88	3.9(7)	17.13(10)	8σ
2.10	4.9(21)	17.06(10)	3σ
Averages	3.6(3)	17.03(11)	
Previous [14]	5.8	16.70(30)	
Previous [28]	5.1	16.94(12)	
Predicted [30]	3.0		

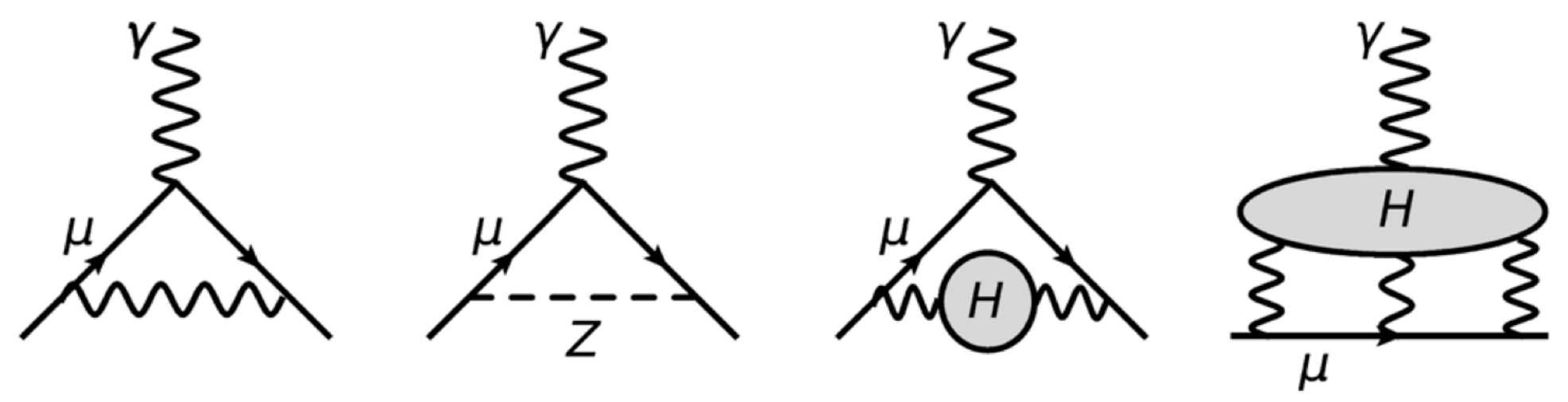


King Plots

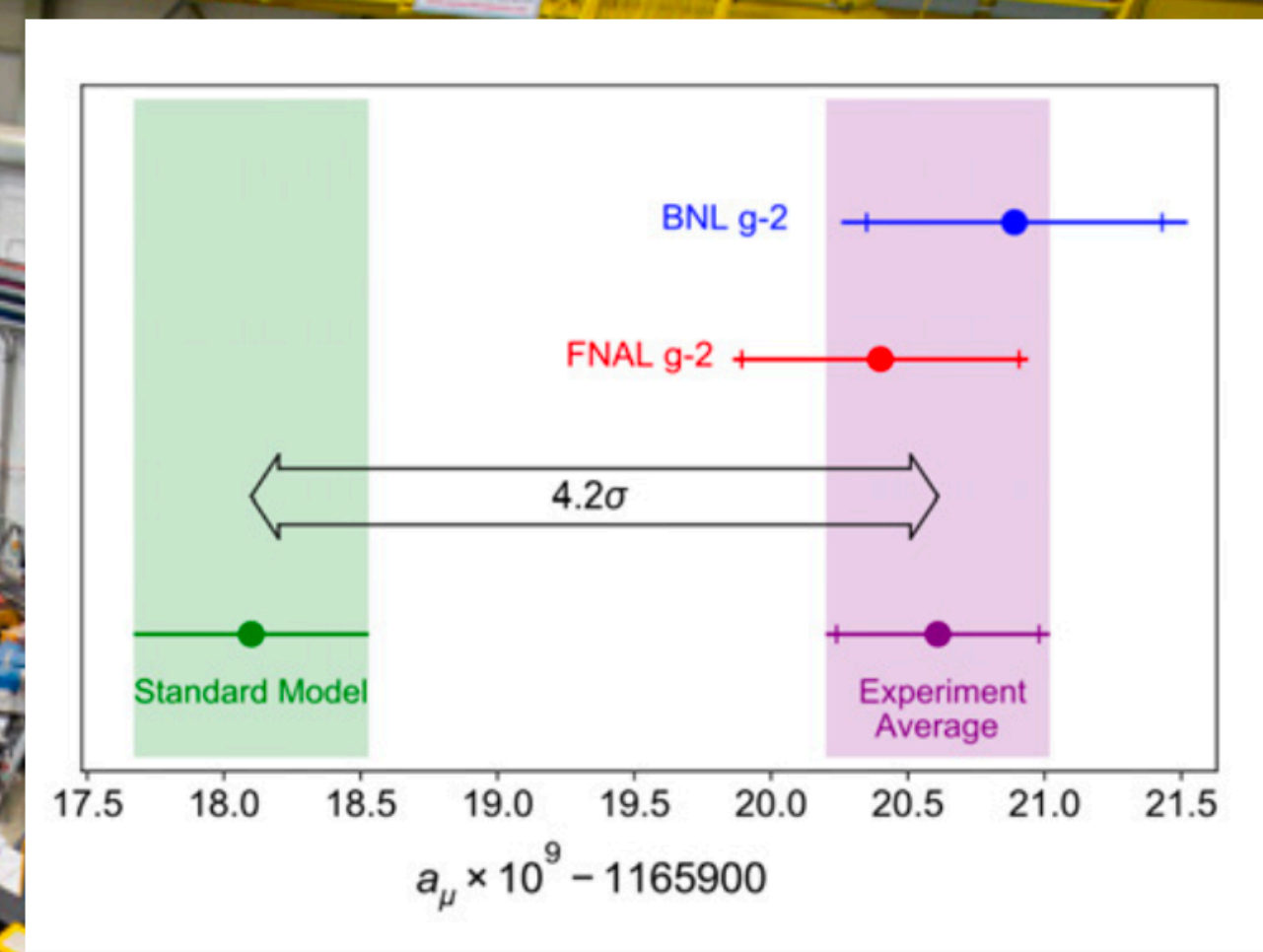
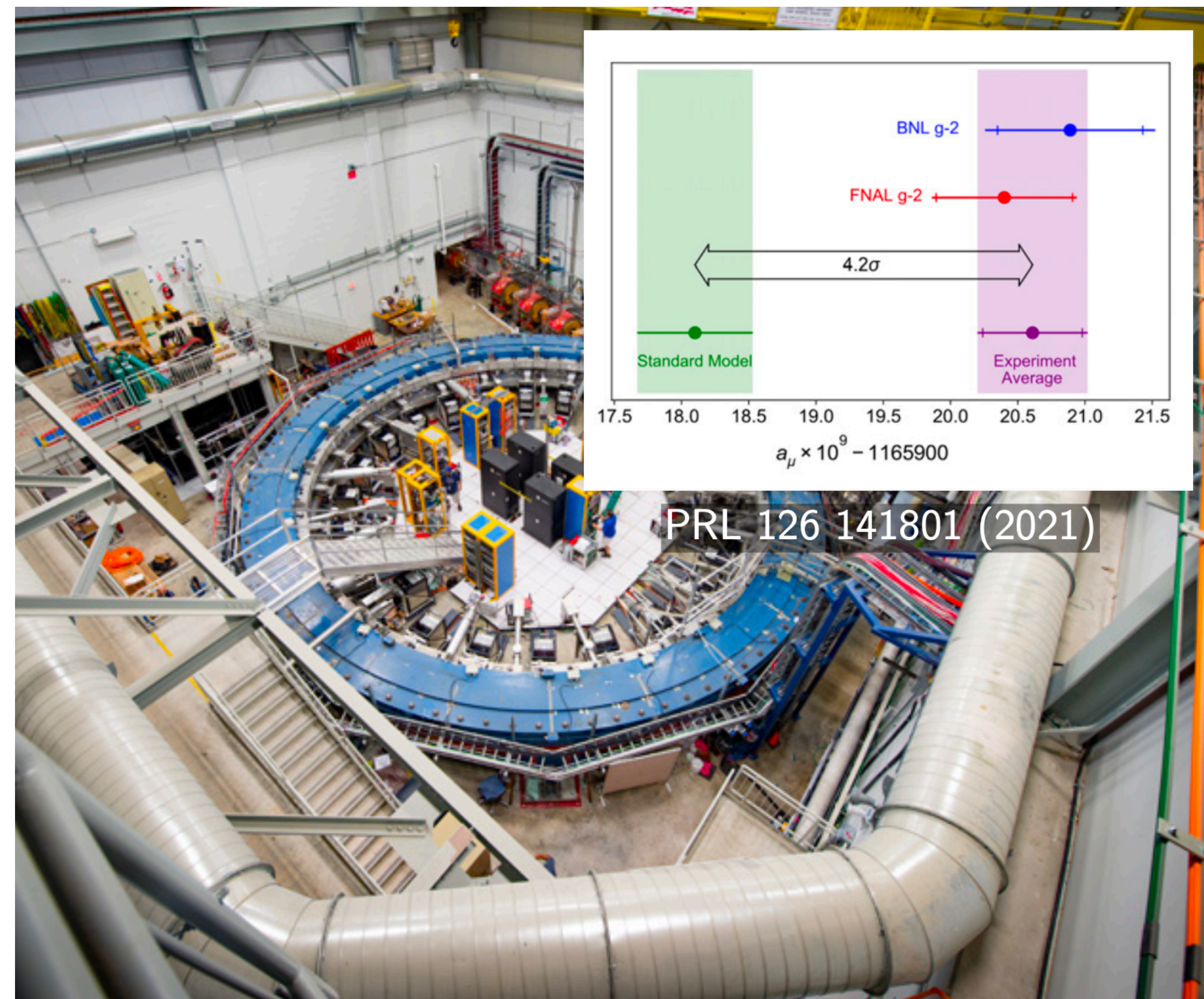
- Various ratio differences combined, plotted as ζ_{\pm}
- Still prefers new physics, but newer results reduce overall significance at $M_A > 1 \text{ MeV}$



Fermilab g-2



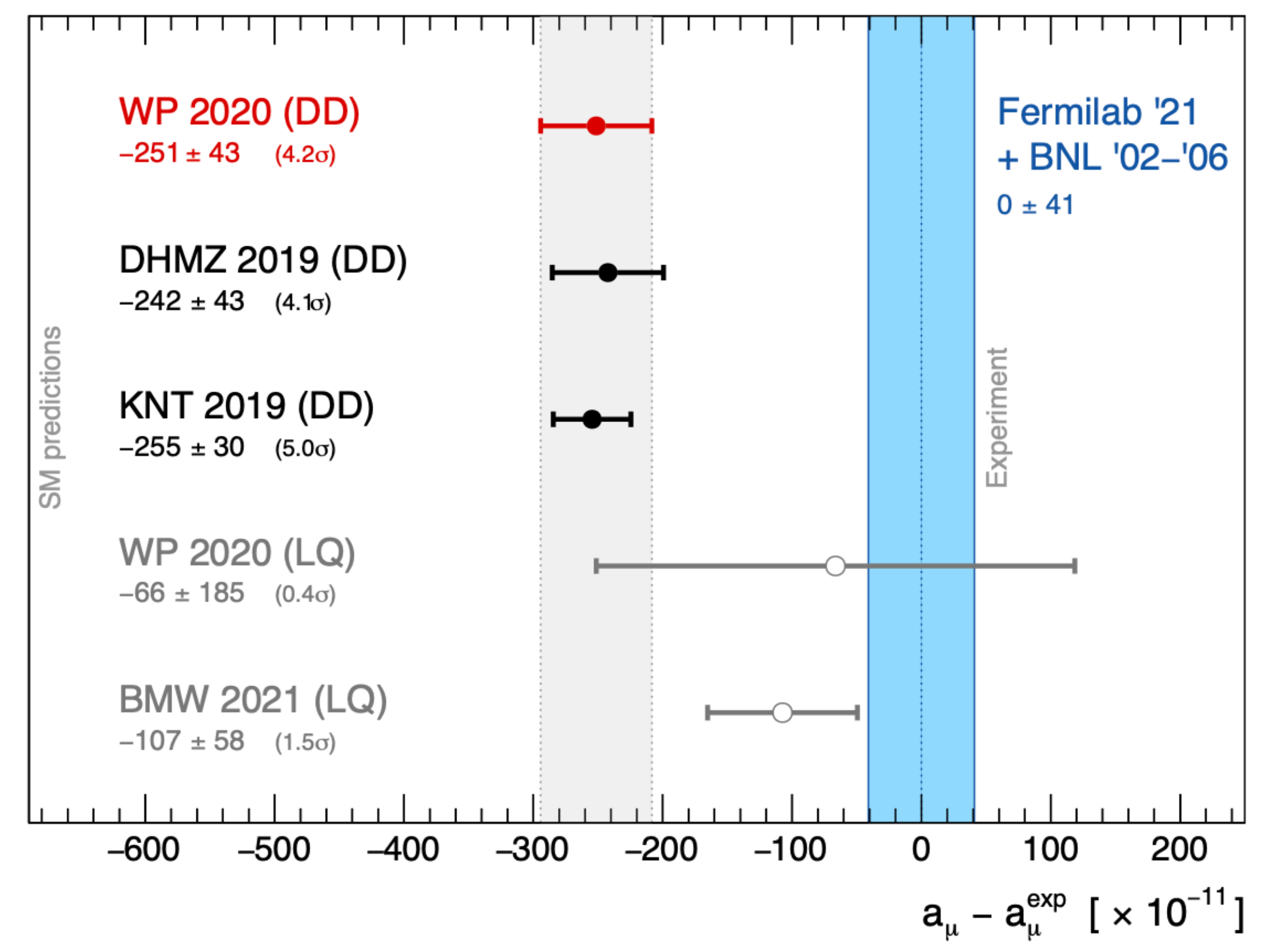
- NLO effects in $\mu\mu\gamma$ vertex drive 'anomalous' magnetic moment
- Measured anomalous moment is anomalously large.
- BSM physics would also appear here too (and generally have larger effect than for electron)



PRL 126 141801 (2021)

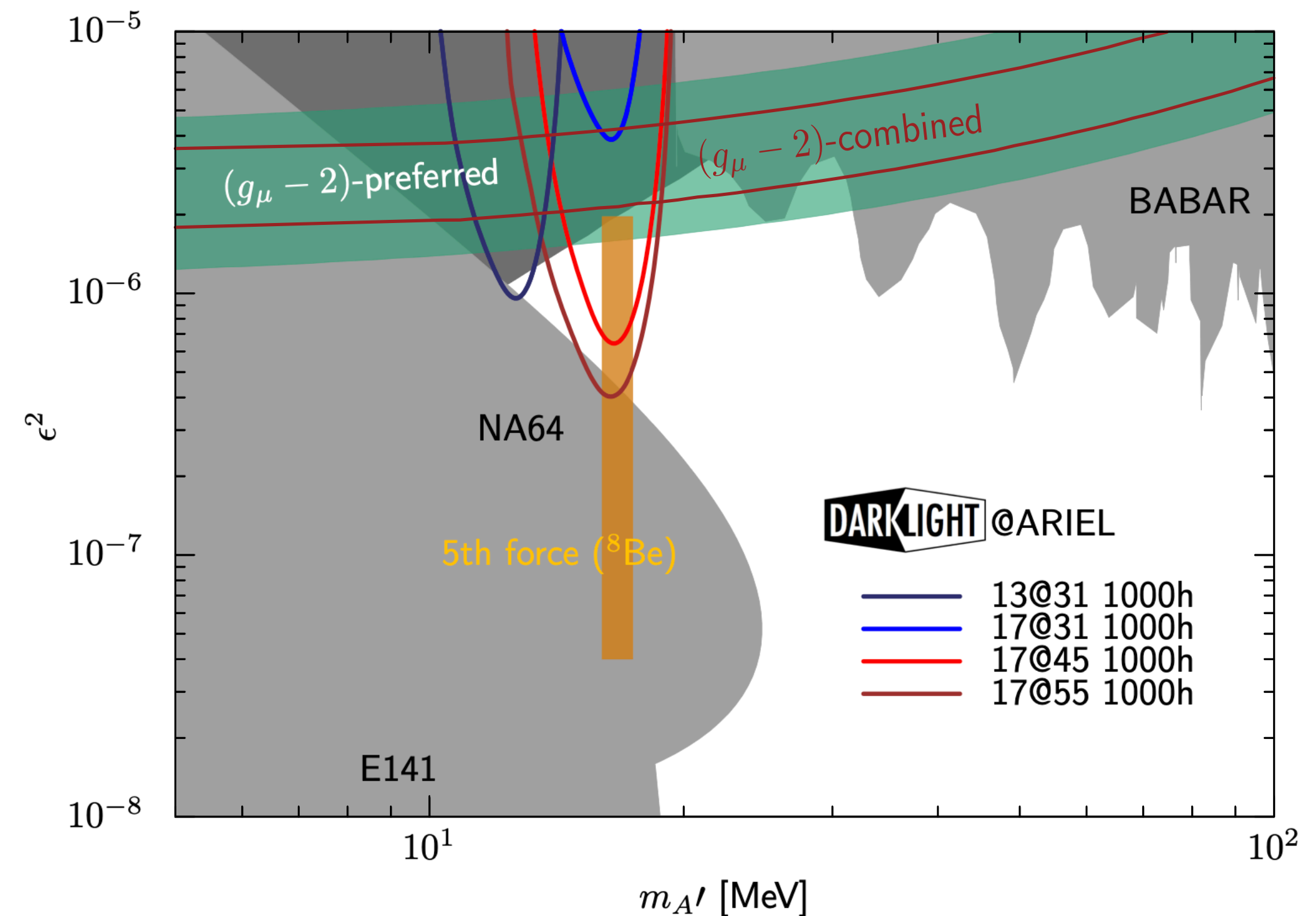
Fermilab g-2

- Data-driven calculations suggest smaller hadronic contribution to magnetic anomaly
- Lattice QCD suggests larger, but caveats. Hence not used in PDG average



Revised $g-2$ region

- Fermilab+BNL reduces preferred band somewhat: no longer touches X17
- *Some* increase from LQCD would move this substantially (or all the way to zero)

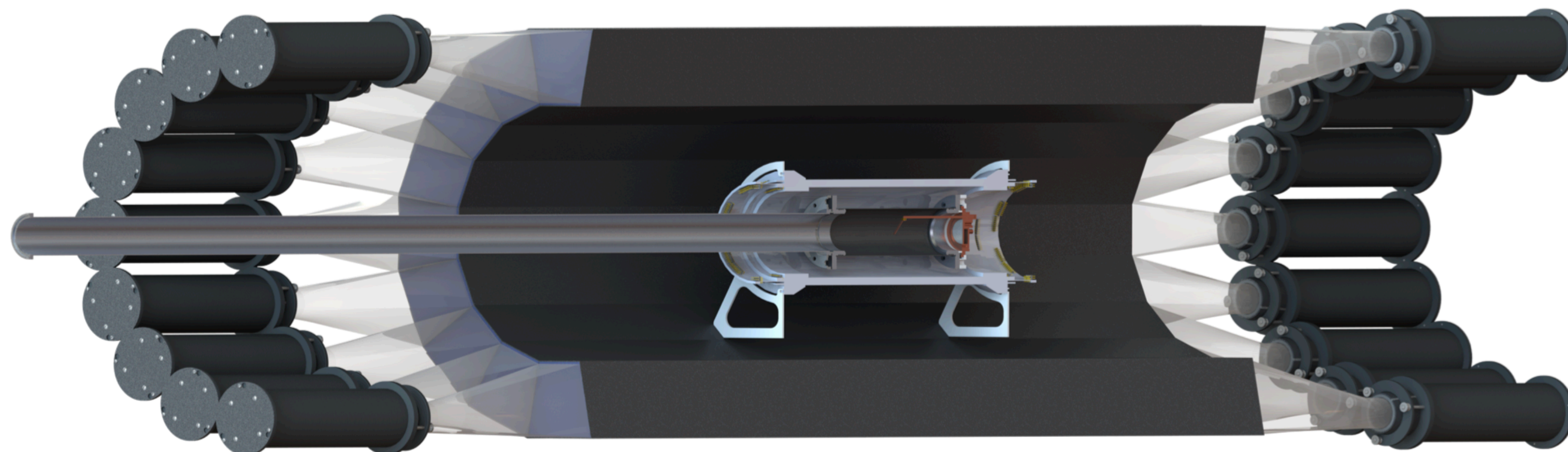


(from our tdr october 18, 2022 version)

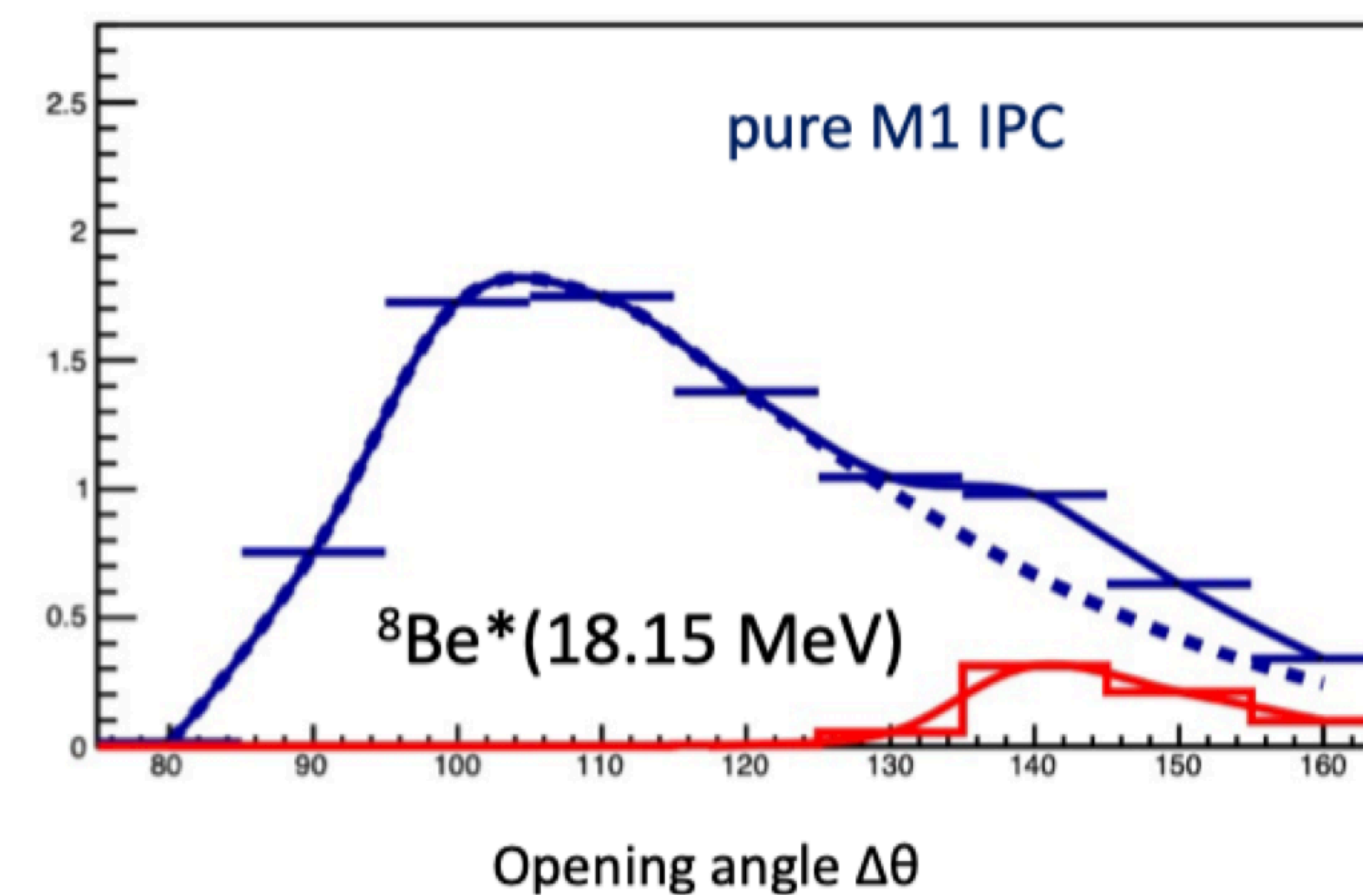
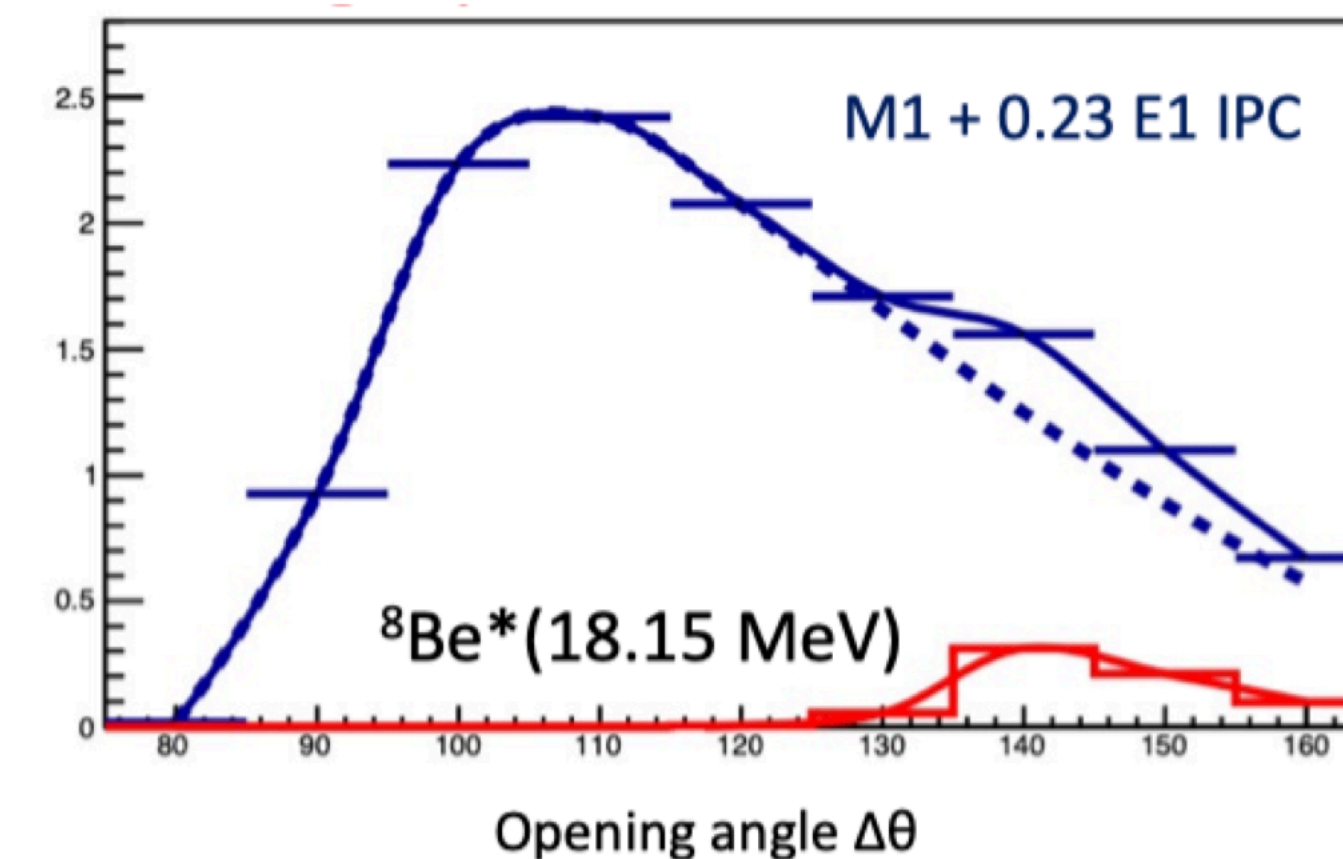
What's New in Searches

- Beryllium:
 - **Montreal** - results in 2023
- General-Purpose Accelerator:
 - LHCb - improved trigger. stats by end of run 3
 - Belle II - stats in 2025 or later
- Dark-Photon Specific:
 - MAGIX - operates 2024+
 - LDMX - operates 2024+, closes from *below*. data hungry
 - NA64 - modified to close the gap
 - APEX - probably can't reach
 - HPS - probably can't reach
 - PADME - modified to close the gap
 - **PRad** - modified to close the gap
 - *et al.*

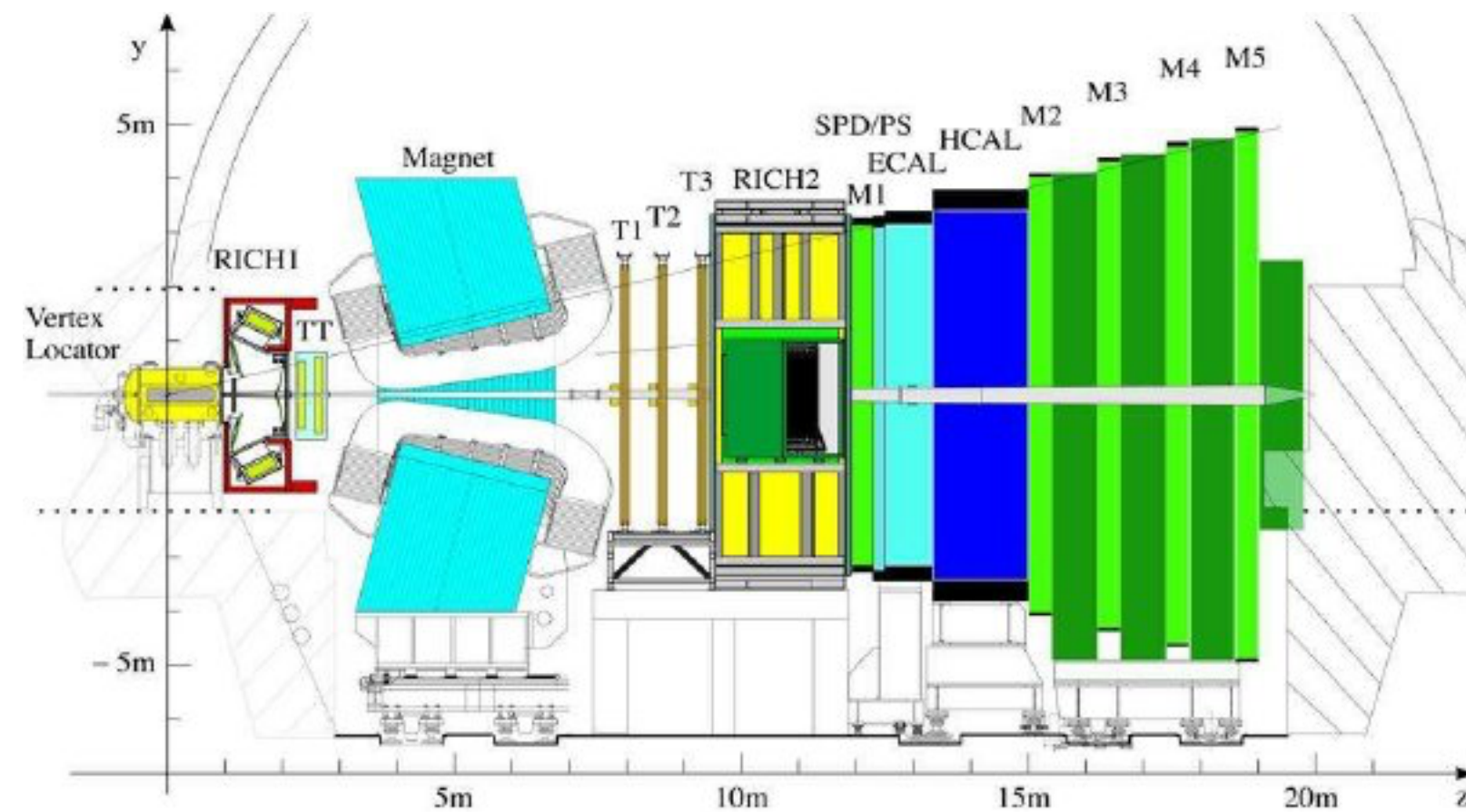
Montreal MWPC



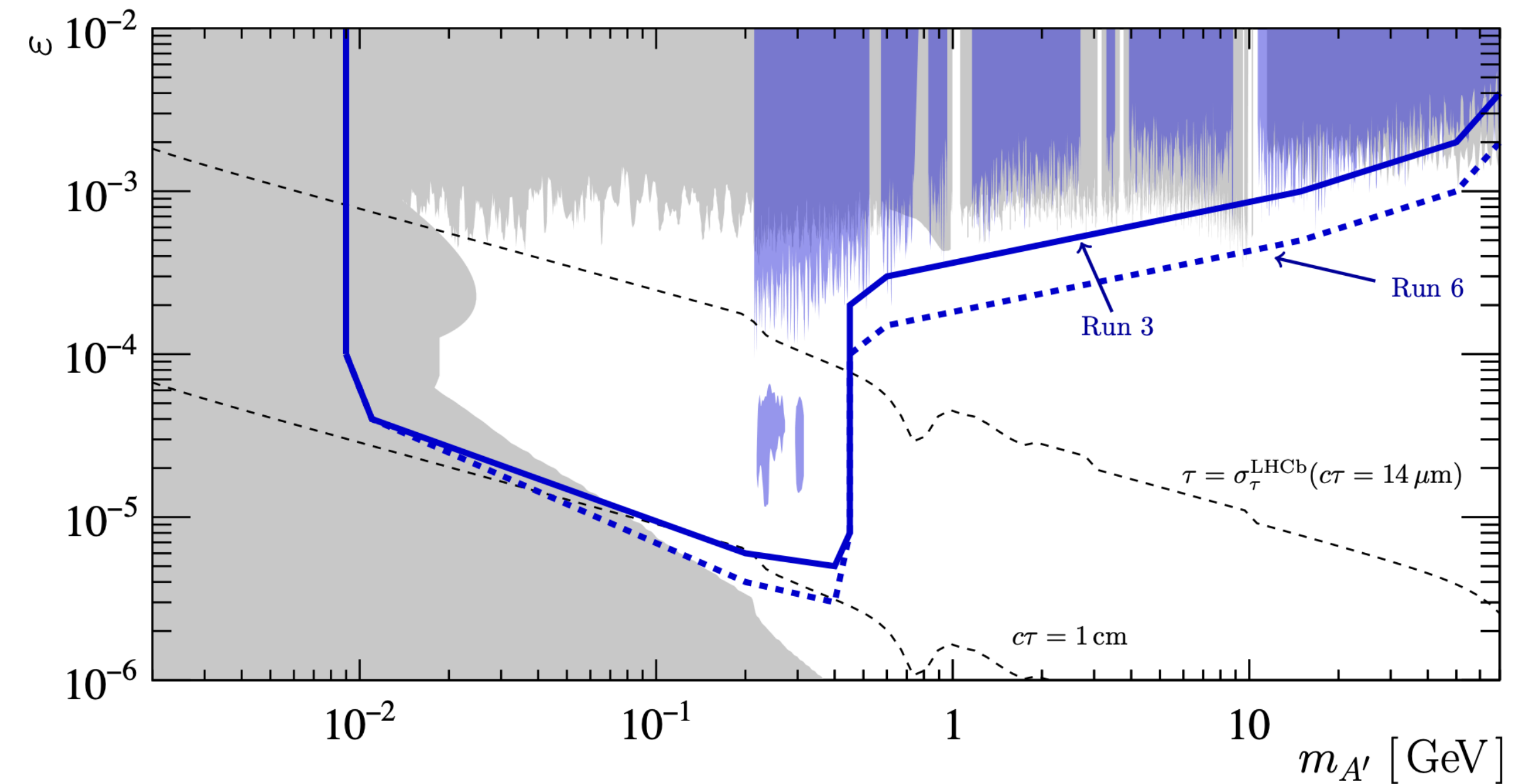
- protons on ${}^7\text{LiF}$ target, similar to ATOMKI
- MWPC surrounded by scintillators provides 95% solid angle
- 9 X17 per hour, if it matches ATOMKI prediction.
Substantial signal in ~2 weeks
- Data taking in 2023



LHCb



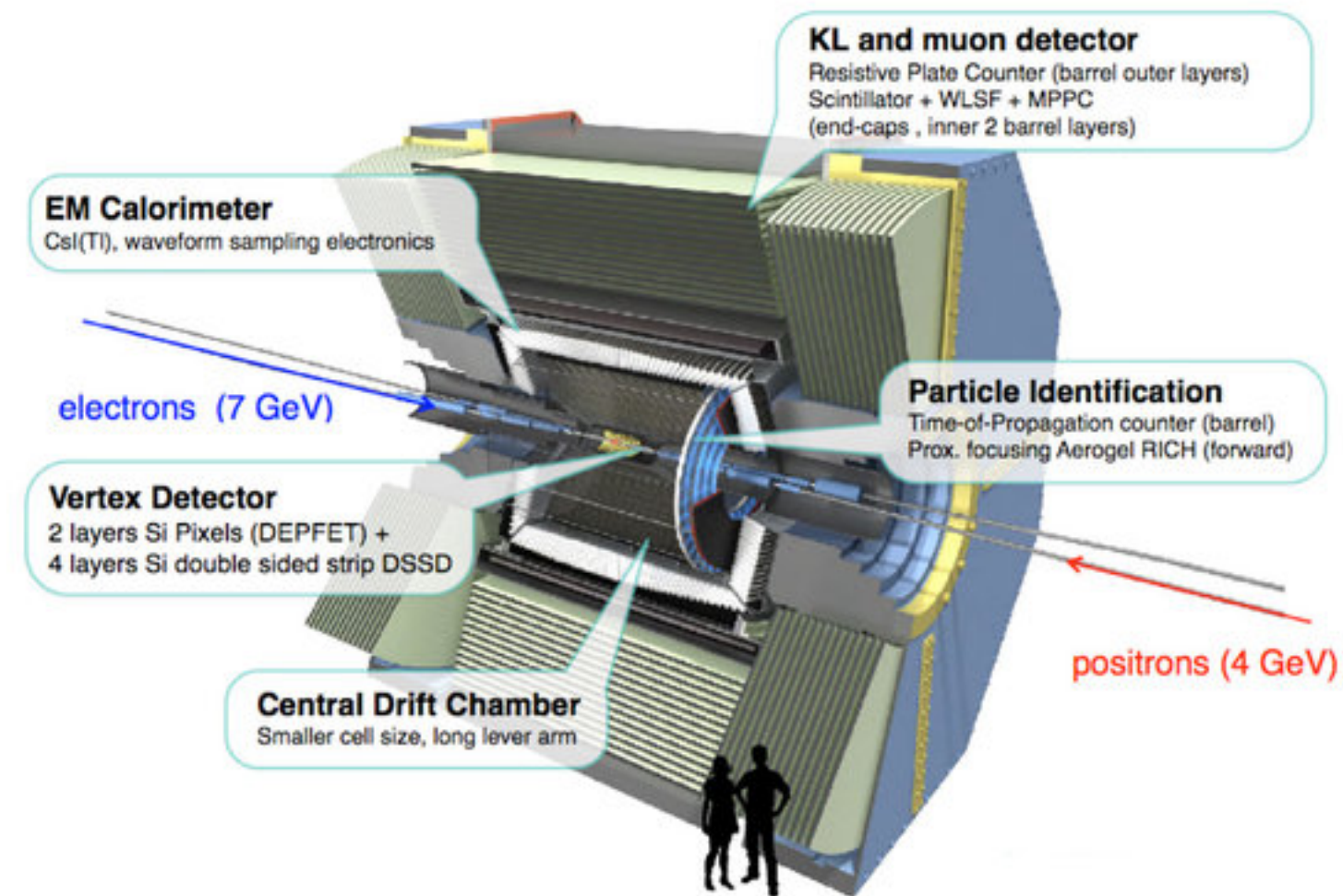
- Upgrade for next run allows softer final states to be recorded
- 'recent advances' in trigger enable e^+e^- final states
- Can exhaust parameter space even with protophobic with sufficient data, (solid blue line, 2022-2026)



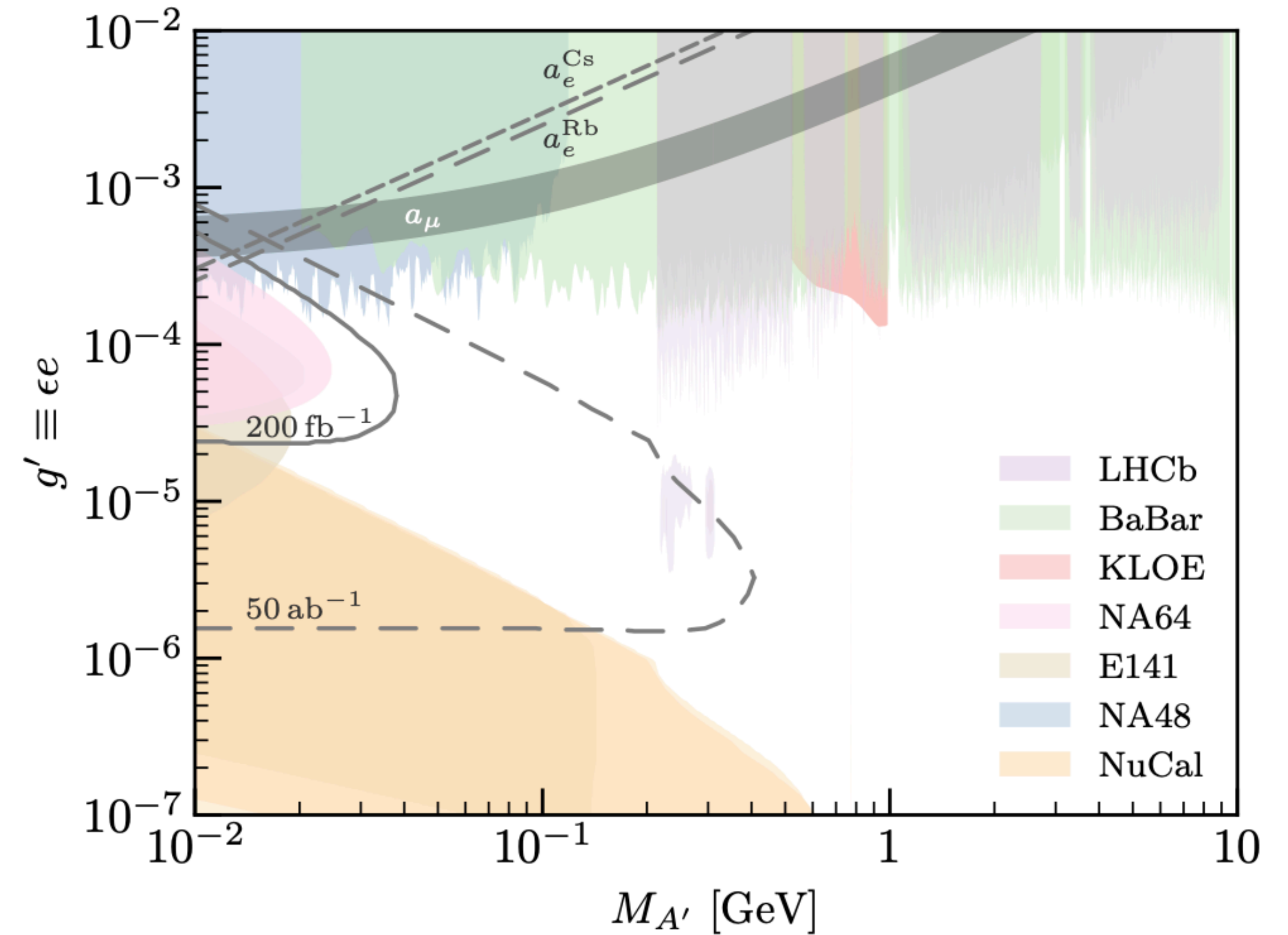
arXiv:2203.07048

(P. Ilten paper (arXiv:1801.04847) allows to recast simple dark photon measurements in more complex models)

Belle-II

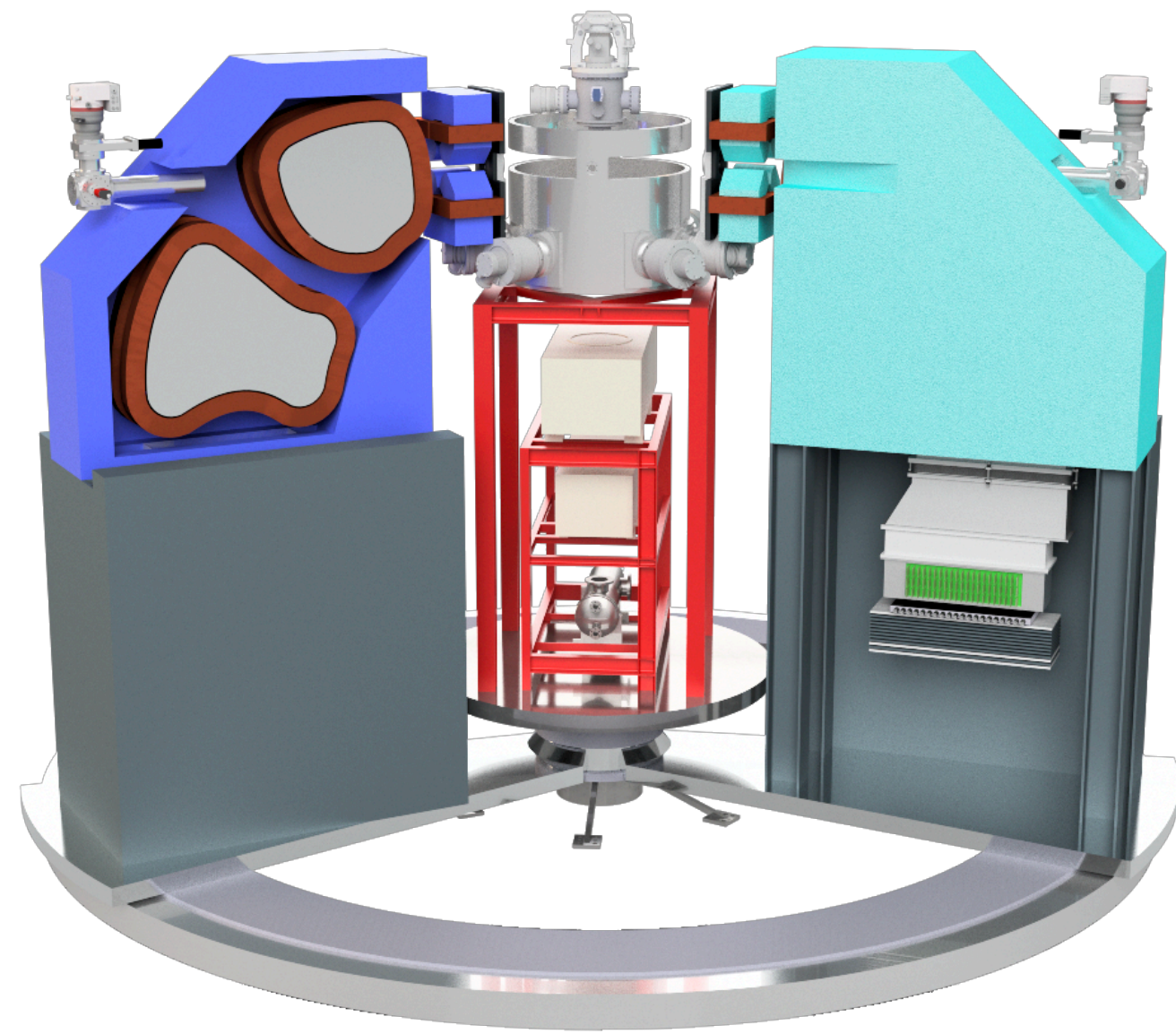


- Direct measurements won't reach down far enough even with full dataset. arxiv.:2012.04190
- X17-specific search (right) uses displaced vertices in J/ψ decay
- $\sim 200\text{fb}^{-1}$ collected **already**, but no published result yet. Full 50ab^{-1} , expected by **\~2025** May barely exhaust X17 region with full lumi.

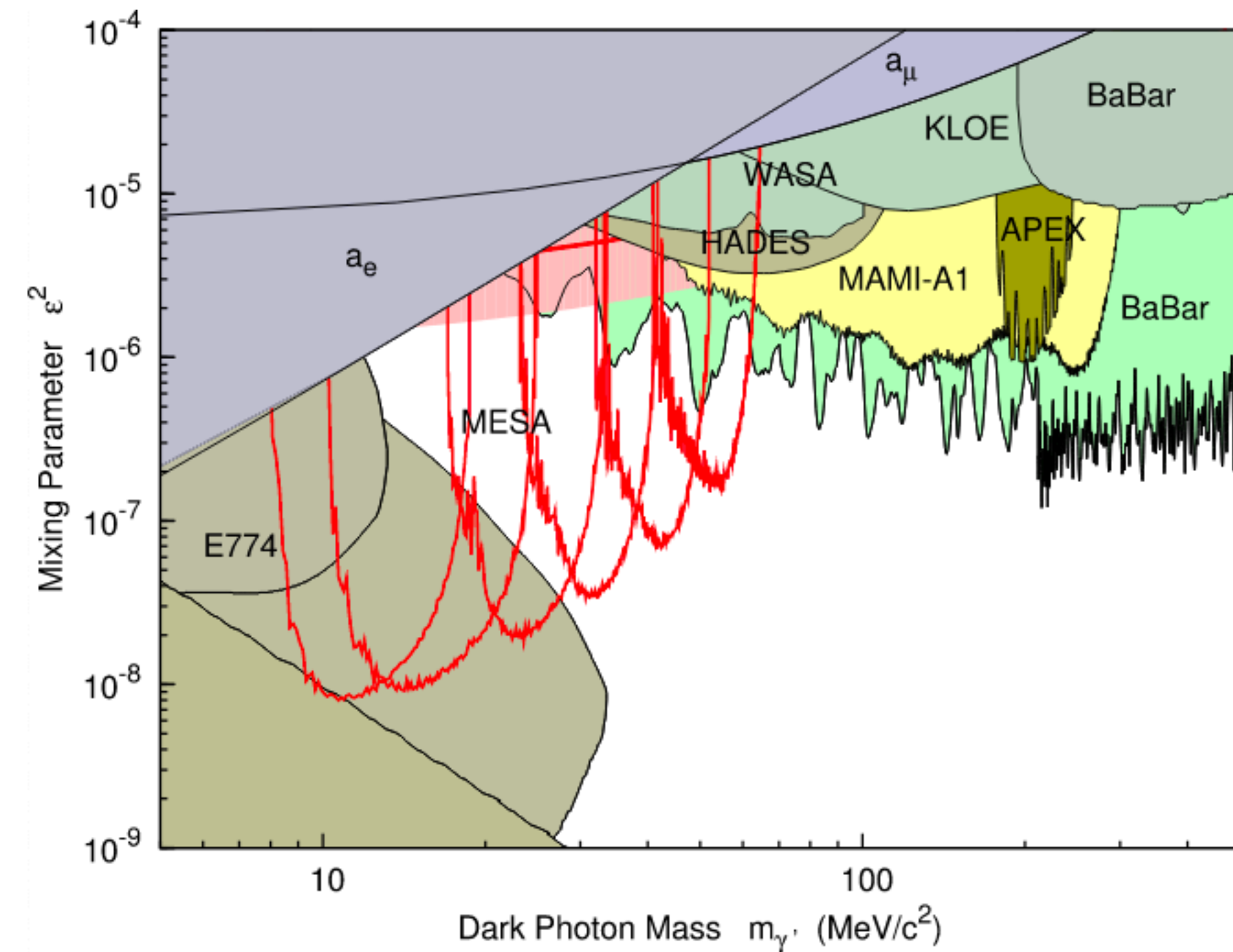


arxiv.:2203.03280

MAGIX



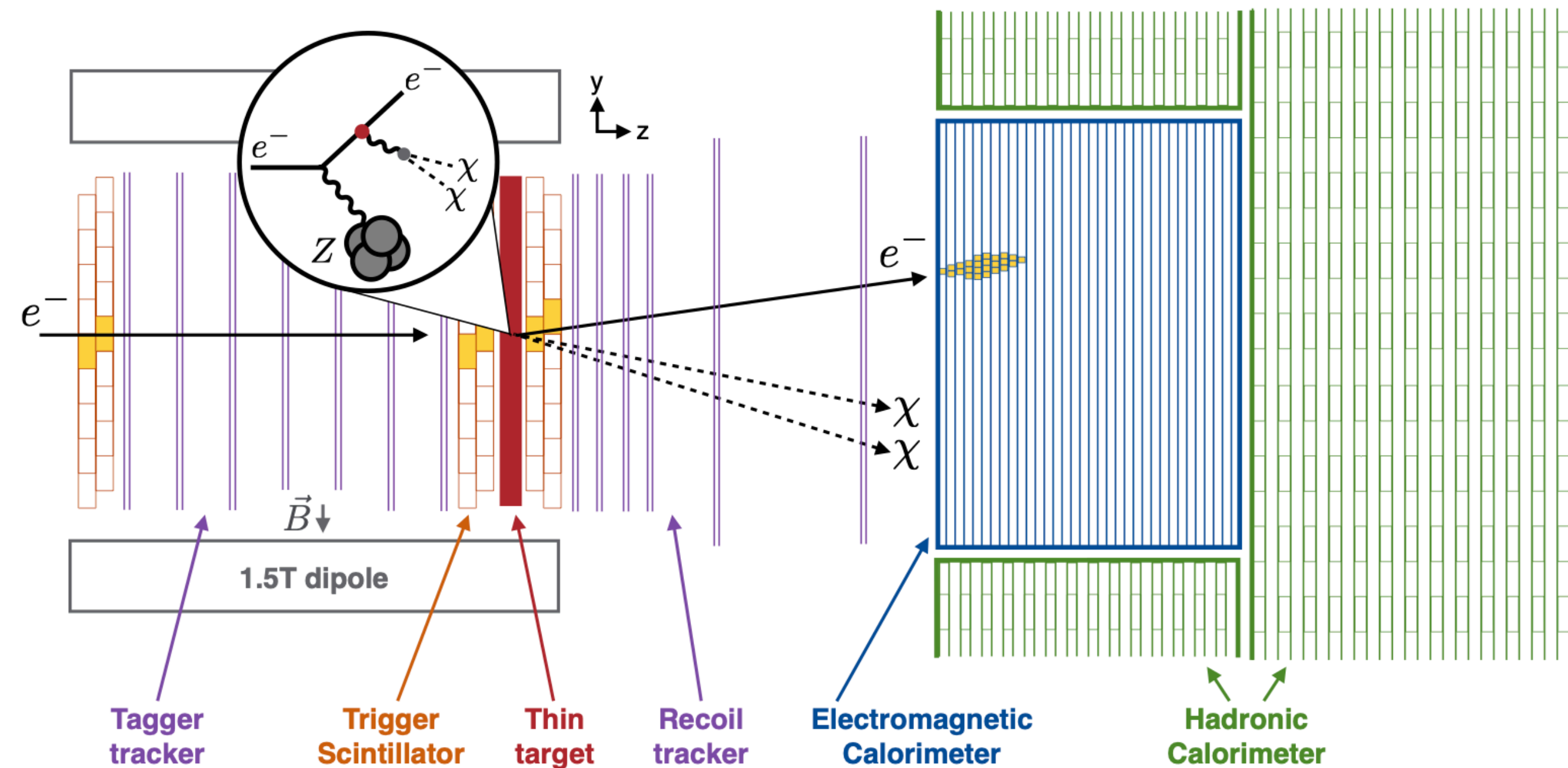
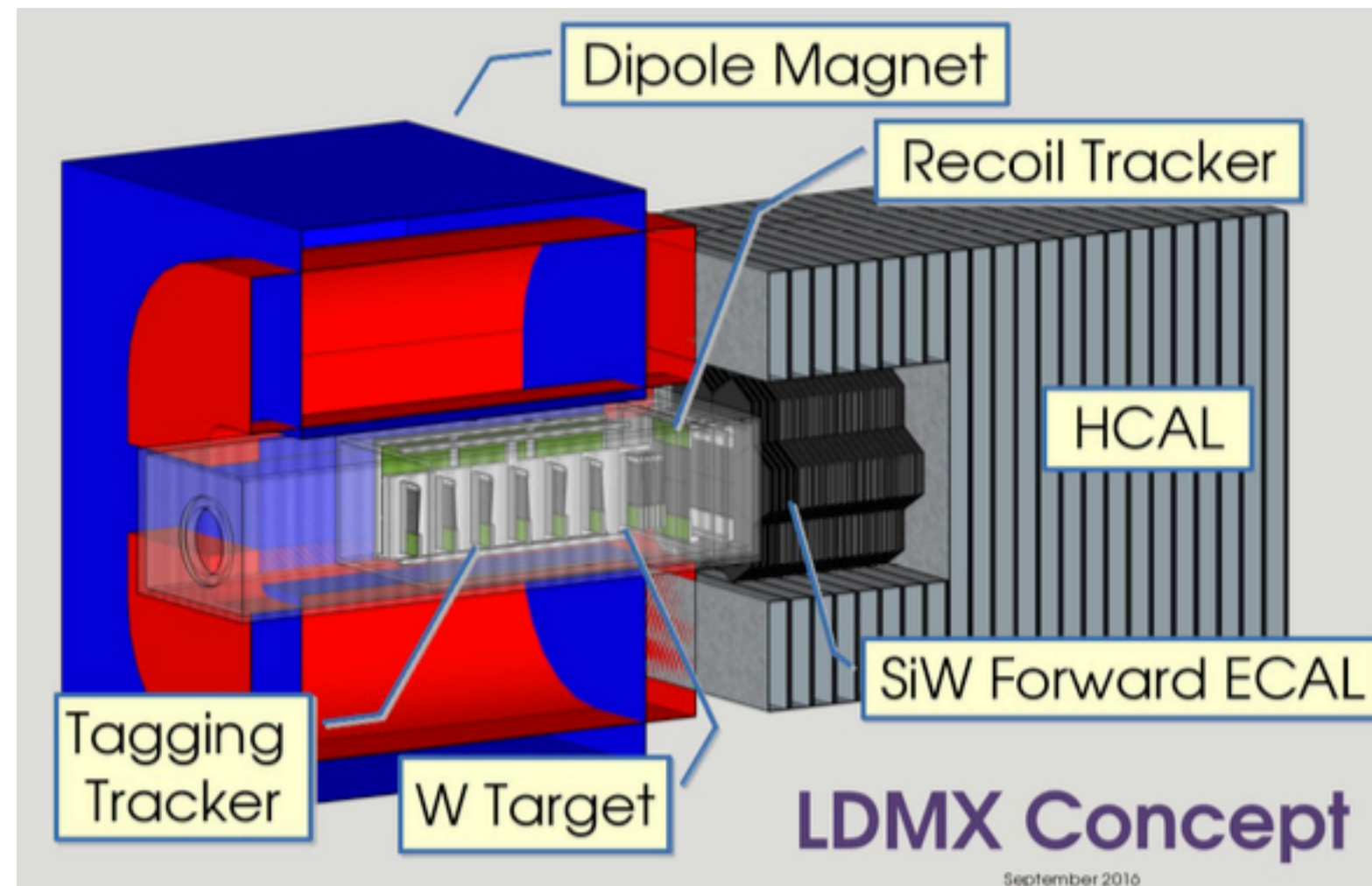
- Twin spectrometer, gas target @ MESA
- Projects to reach X17 anomaly region w/ ~6mo at design luminosity
- MESA first beam ~2024, MAGIX start-up "shortly after"



<https://magix.uni-mainz.de/physics.php>

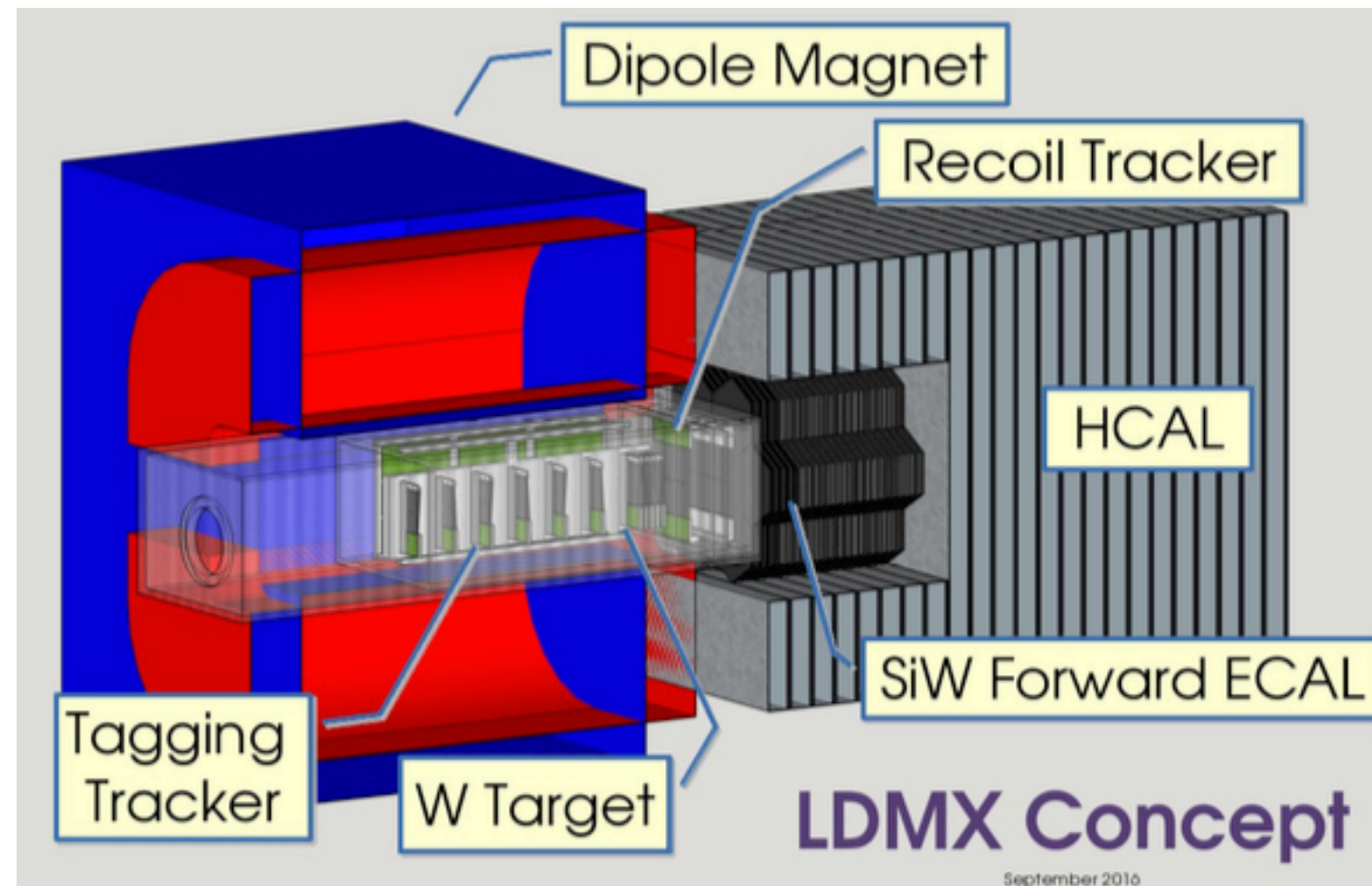
<https://www.mesa.uni-mainz.de>

LDMX

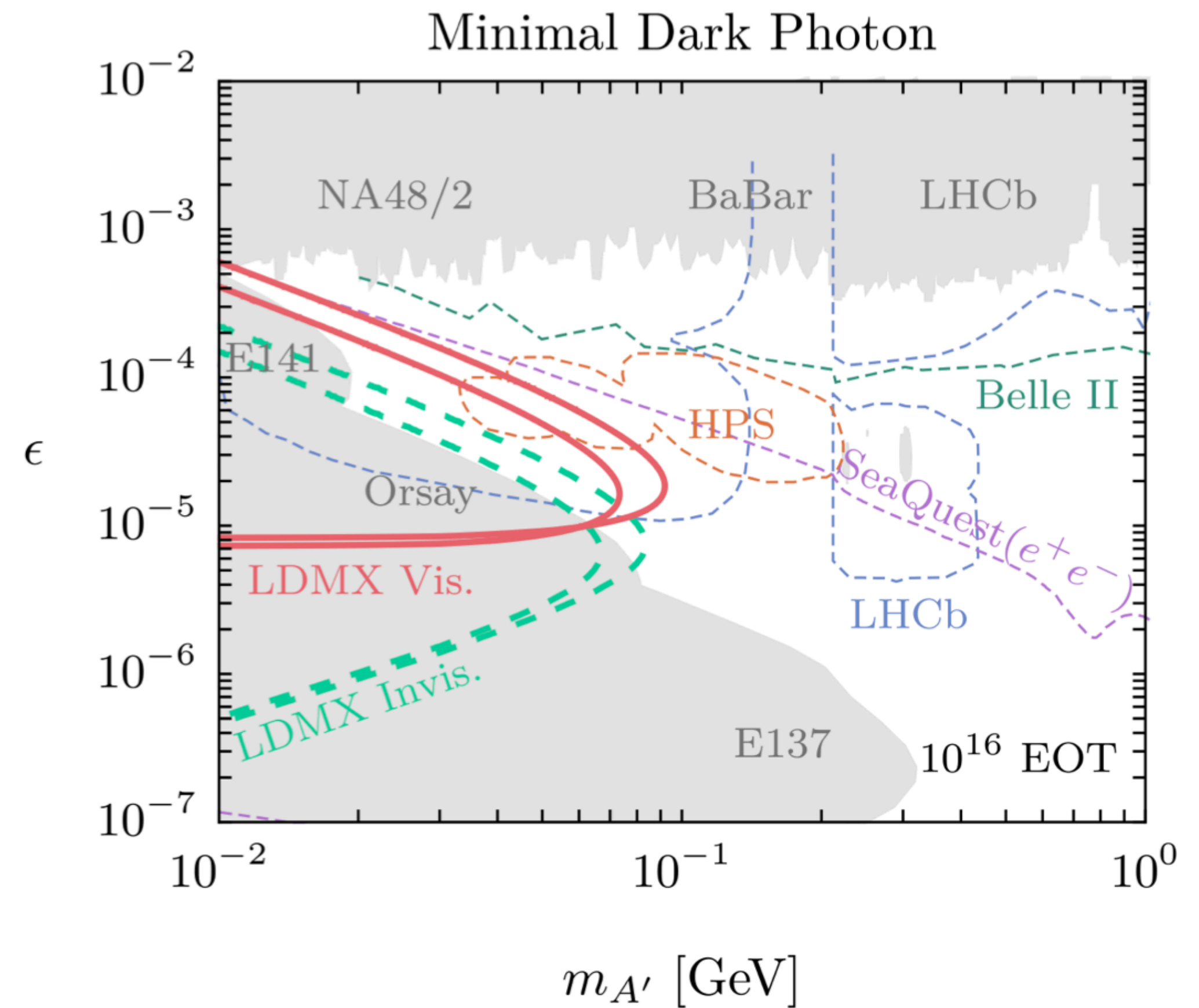


- LCLS-II (SLAC) produces low-current, parasitic multi-GeV e^- beam
- Reconstruct e^- and recoil nucleus to detect invisible final states

LDMX

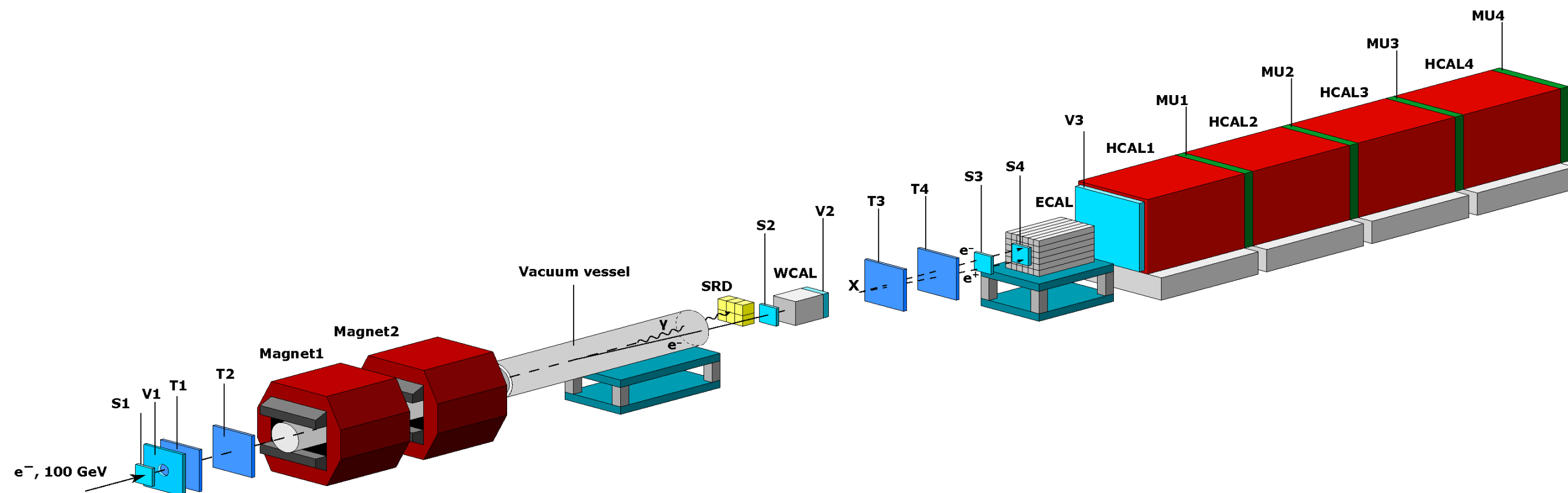


- Primarily missing-momentum experiment. @ SLAC
- Model-dependent search via invisibles.
- Can do displaced vertices, but doesn't expect to reach useful range -- even in high integrated luminosity assumption
- Potentially starts in 2025, several year run to reach full 1 e.o.t. shown in plot

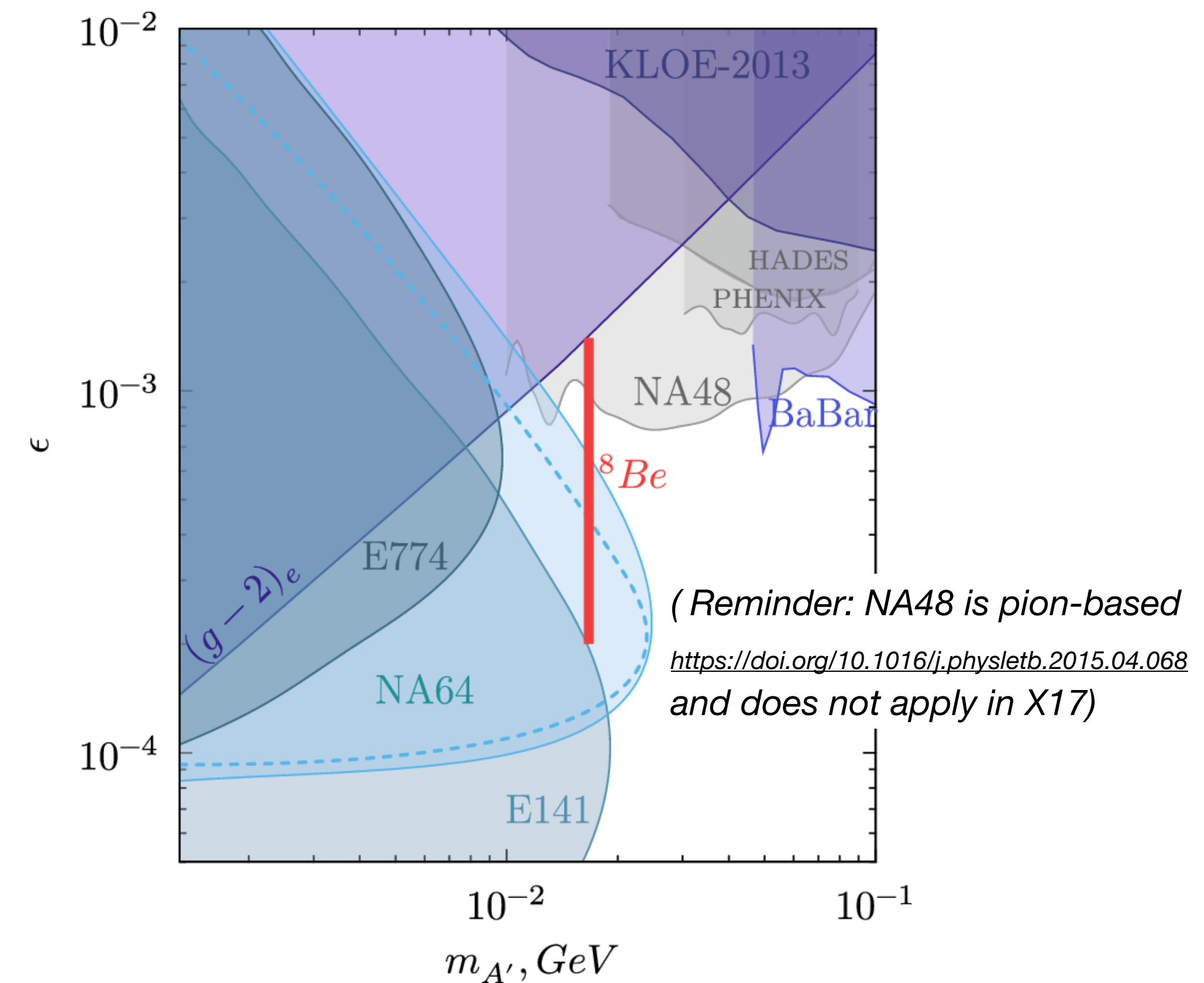


arxiv:2203.08192

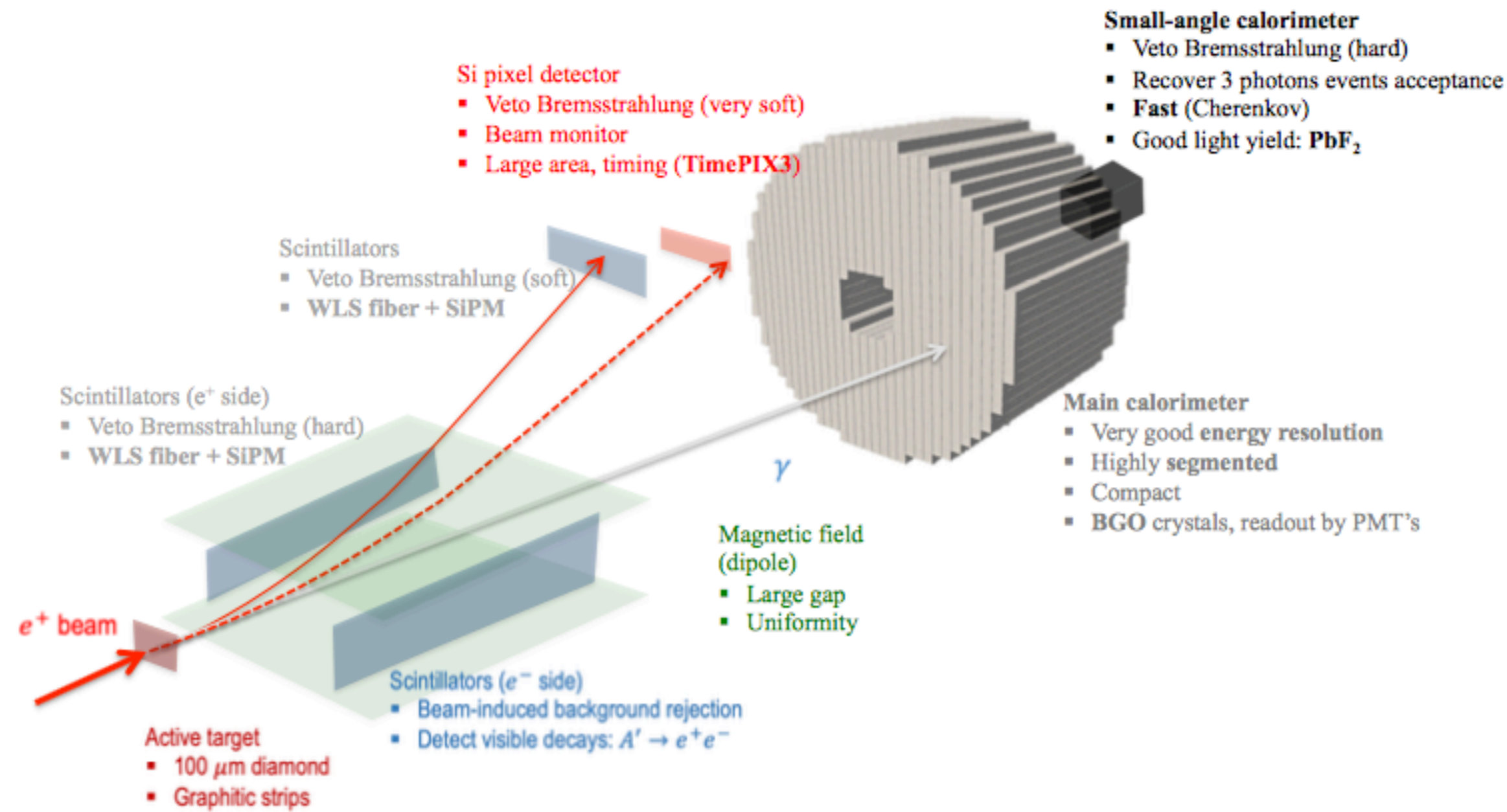
NA64



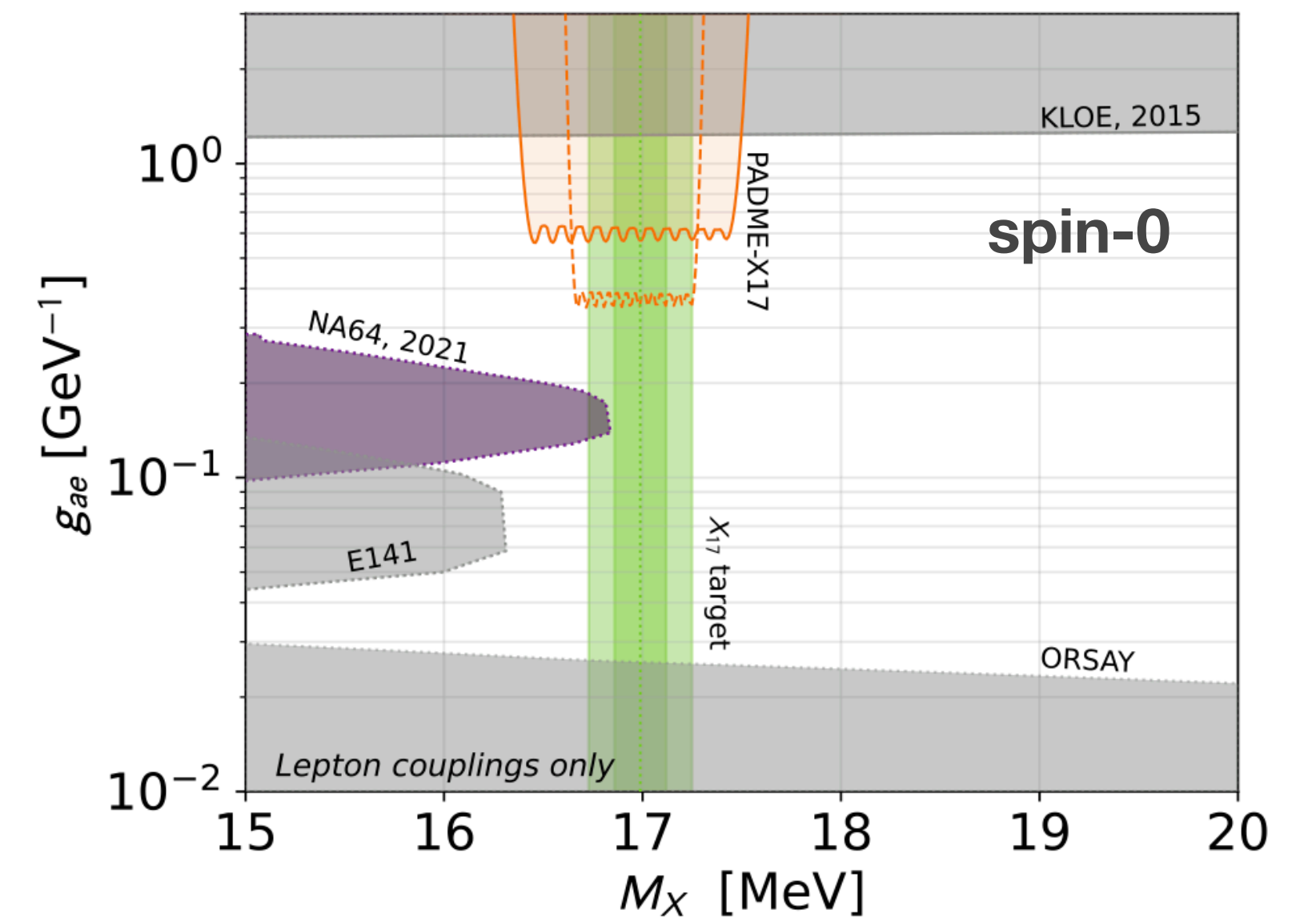
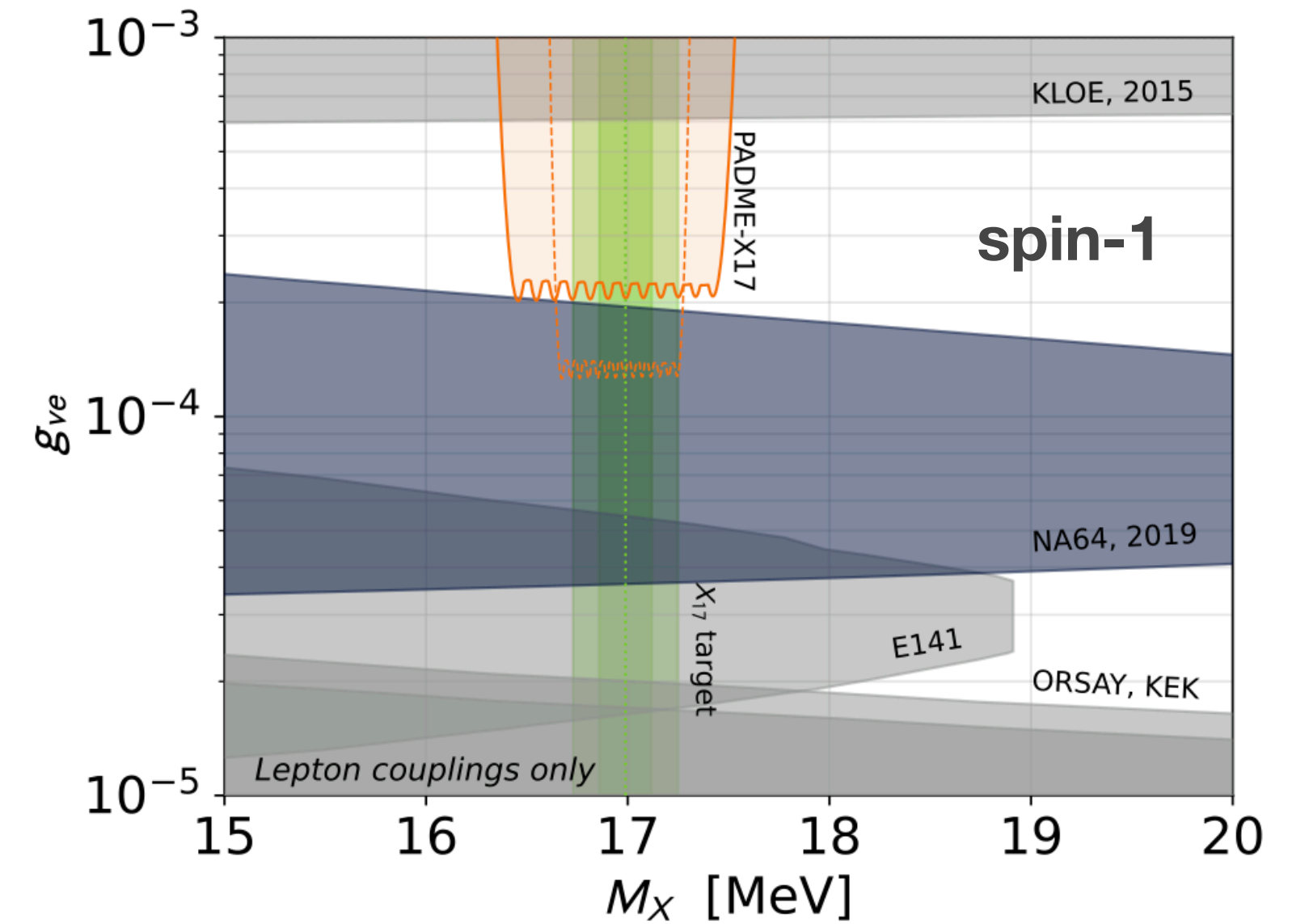
- e and mu fixed target experiment (SPS)
- 2020 combined analysis covers much of original ${}^8\text{Be}$ coupling range
- Upgrade of WCAL and magnet makes remaining X17 accessible (arxiv:2009.02756)
- Visible search planned for 2023 (as of 2022)



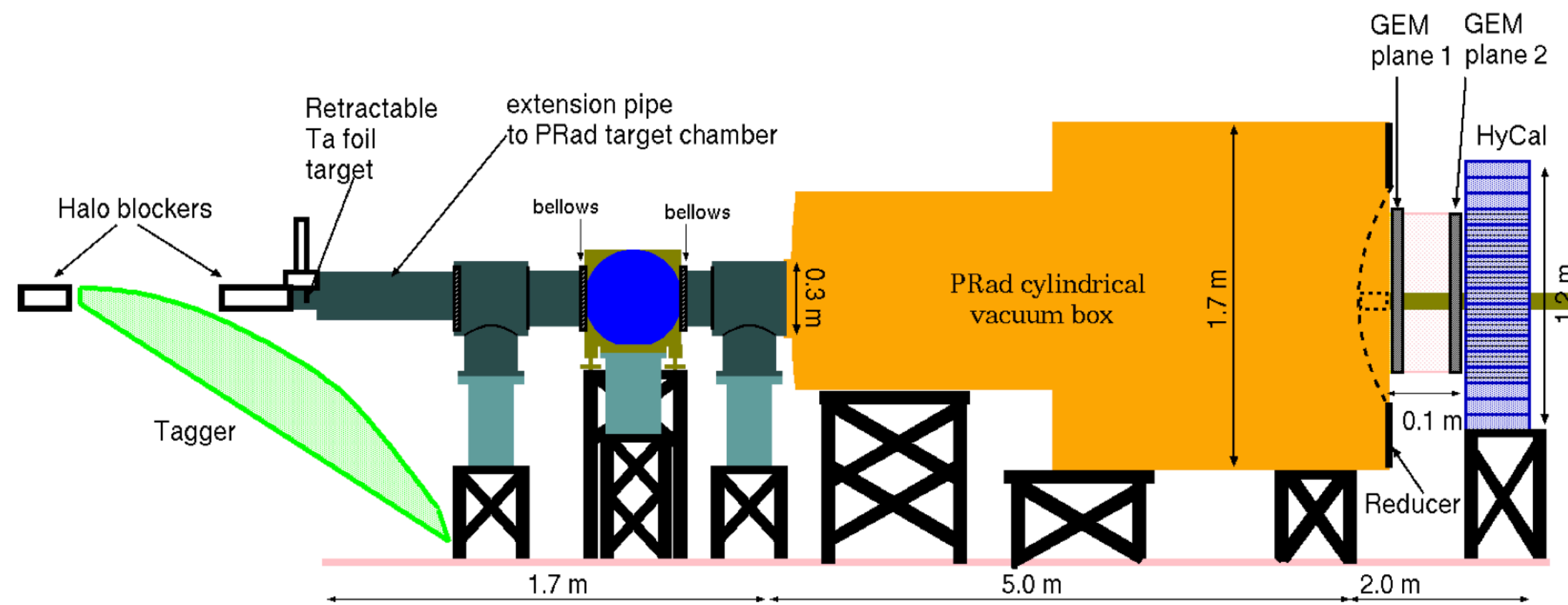
PADME



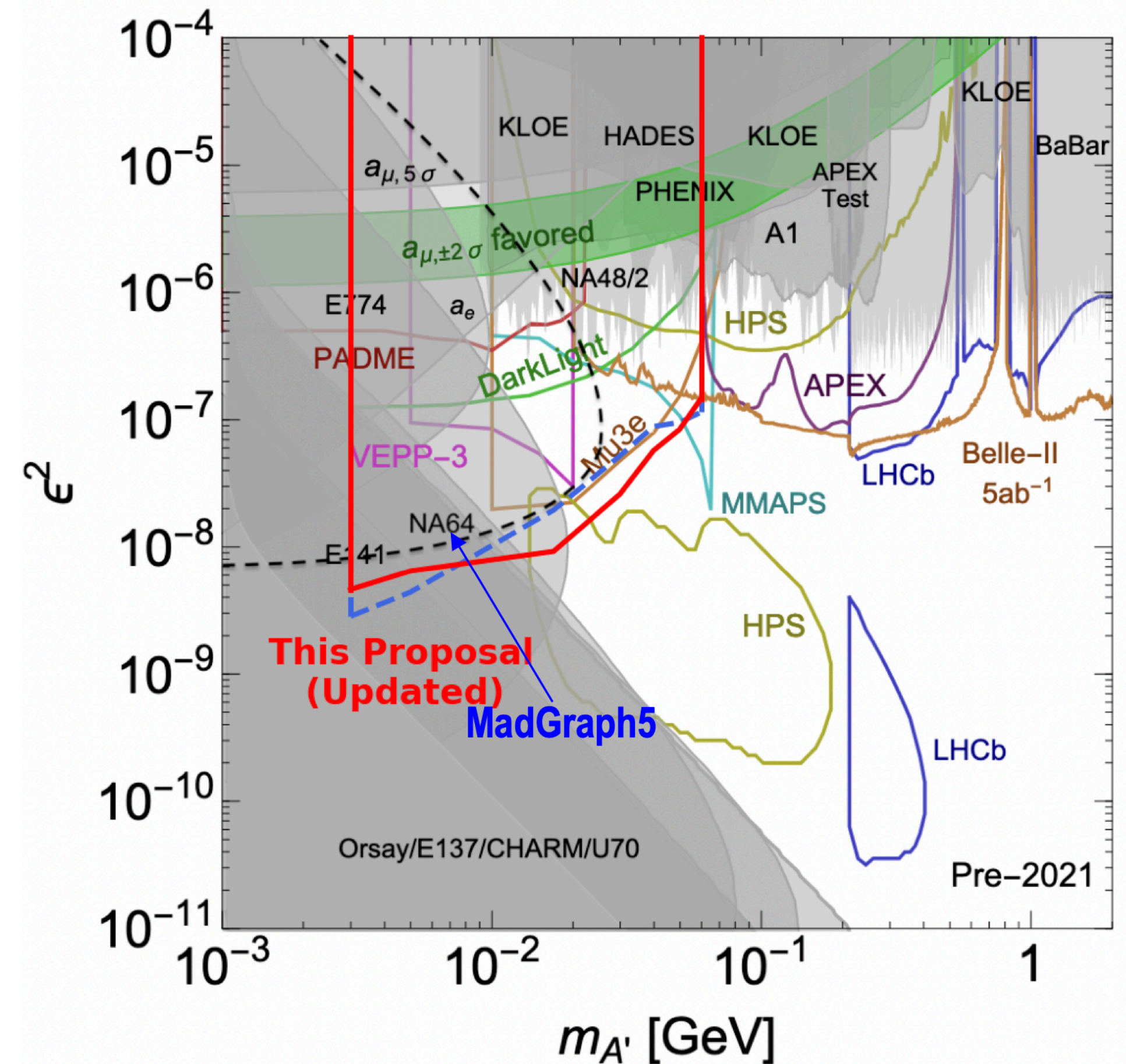
- Positron beam, missing mass technique (DAΦNE)
- New ETag detector to separate e^\pm/γ
- Run 3 (2022-) dedicated to X17: scan across mass range
- "few weeks" of data to cover remaining vector X17 space, if systematics favorable.



PRad



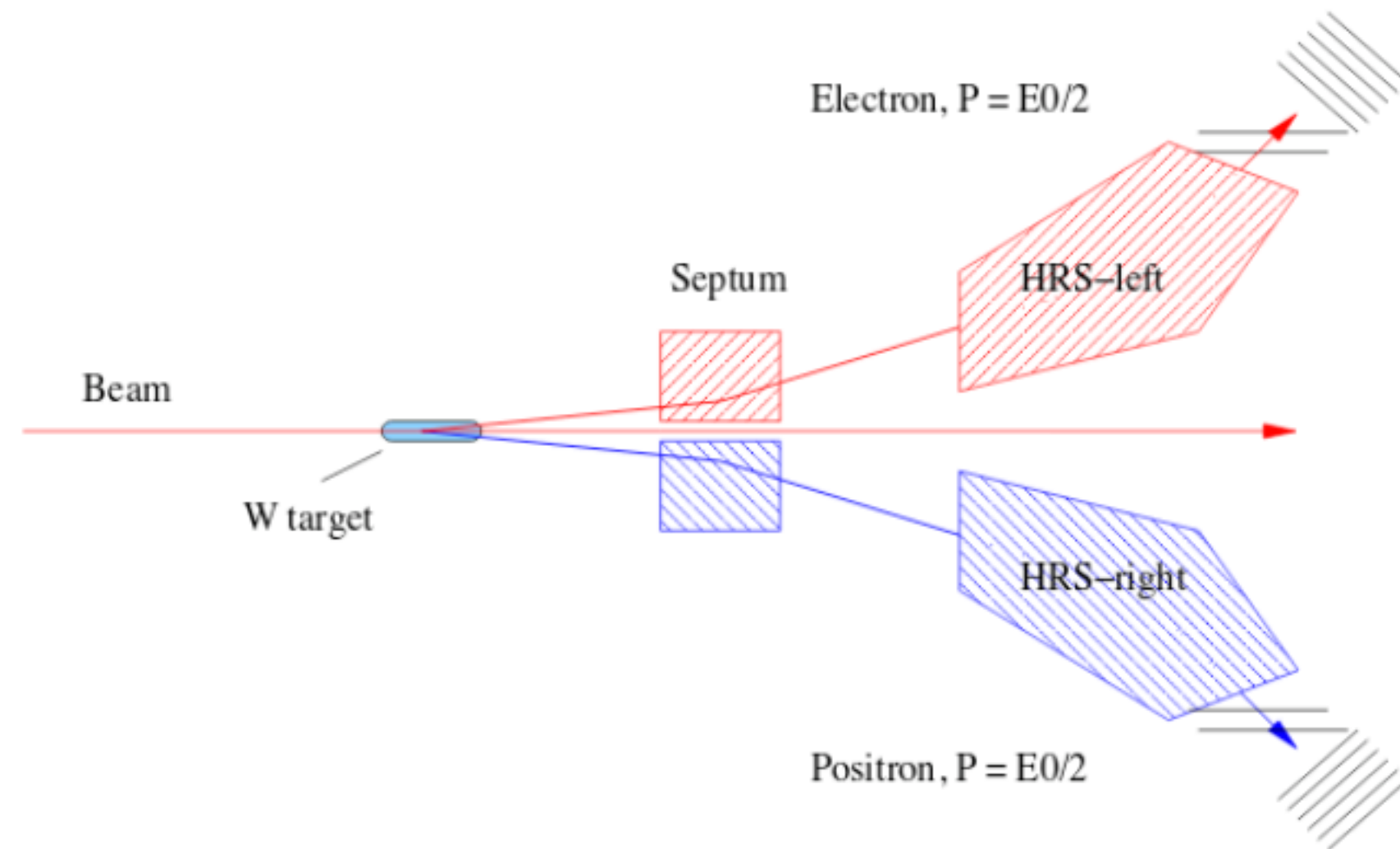
- Detect full $e^-e^-e^+$ in fixed target e^- (JLab)
- Add γ -tagger, μm Ta targets, GEM tracker planes
- Projection of 5σ coverage with 60 day run
- Approved for 60 days, PAC50
- Timeline unclear



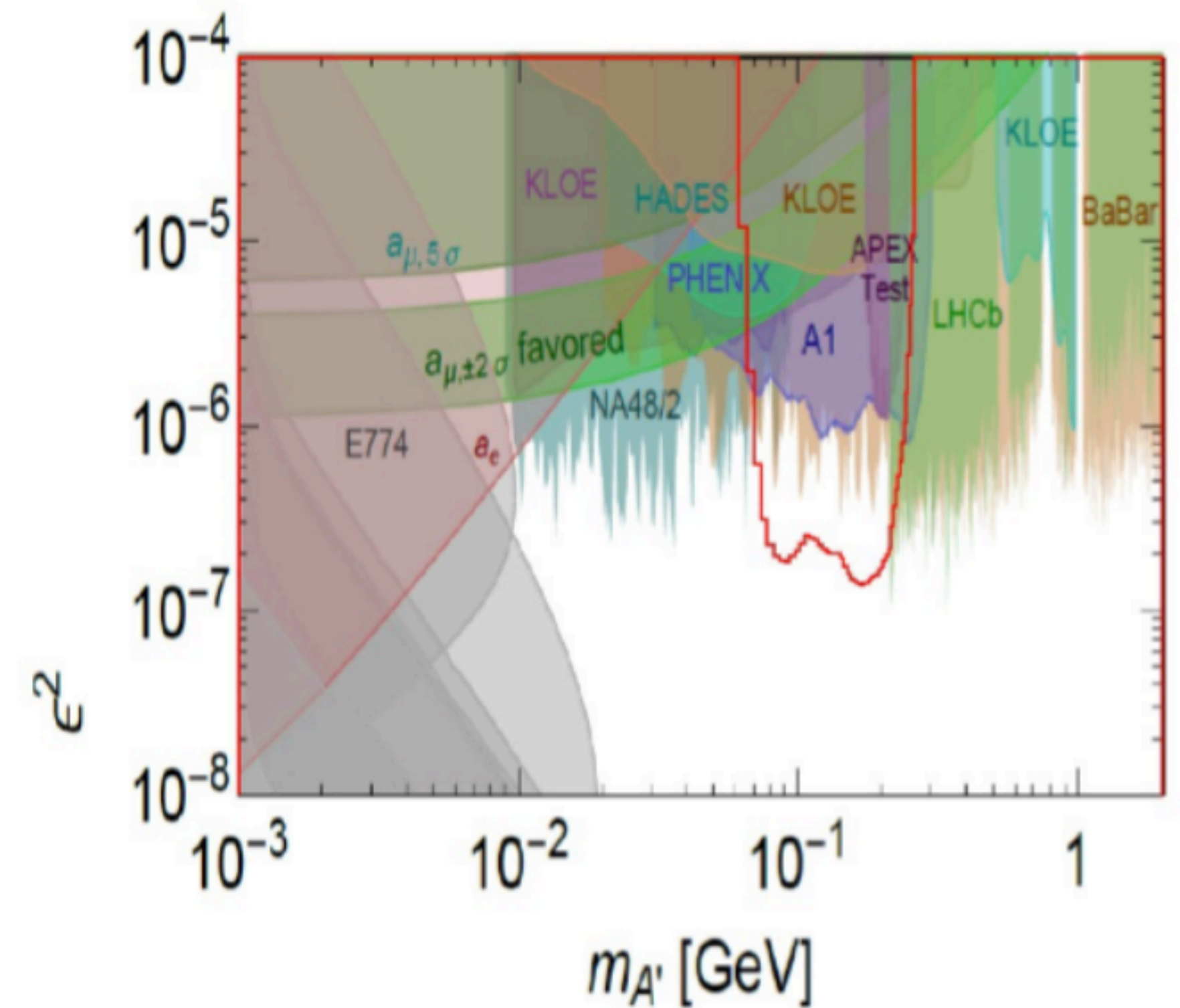
Summary

- Anomalies persist, and a conclusive explanation does not yet exist.
- Many experiments are retooling to reach this region in the near future.
- In some cases, these will provide complementary coverage with DL@ARIEL
- *"This [area] is exciting and timely. The measurement/search is needed, and it will receive significant attention if completed before their competitors."*

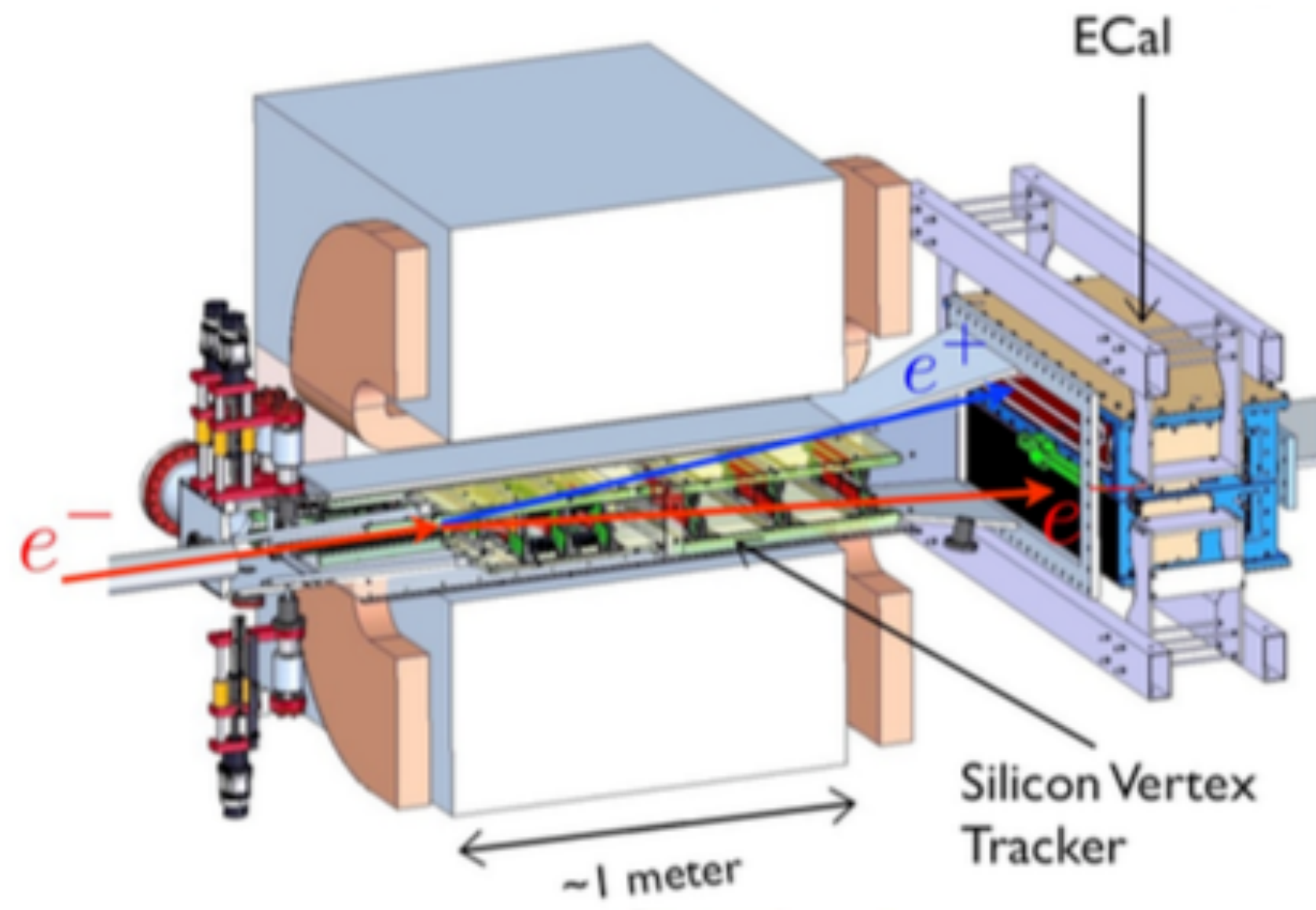
APEX



- e^+e^- mass resonance, very low opening angles
- Plot includes 2020 data and future proposed settings -- current design can't reach X17



HPS



- Tracking very close to target+beam
- Prompt and displaced vertices for SM decay
- Can't reach <20 MeV without modification.
- Lower energy? Haven't seen this proposed

