DarkLight Experiment

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TRIUMF

Lake Louise Winter Institute
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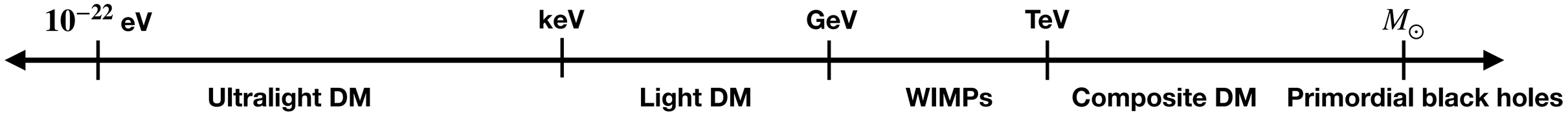
Discovery, accelerated

Introduction

- DarkLight@ARIEL is an ongoing experiment based at TRIUMF in Vancouver, Canada
  - Built upon a previous experiment performed at JLab
  - Previous update given at LLWI 2023 by Dr. Kate Pachal
- Searching for low mass e^+e^- resonances
- Outline: Physics motivation → Apparatus description → Current status

Background

- Dark matter is one of the big unanswered questions of particle physics



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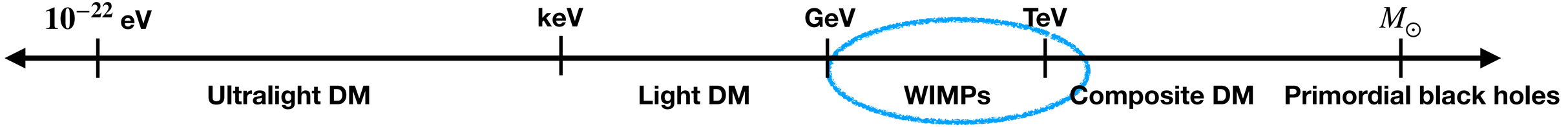
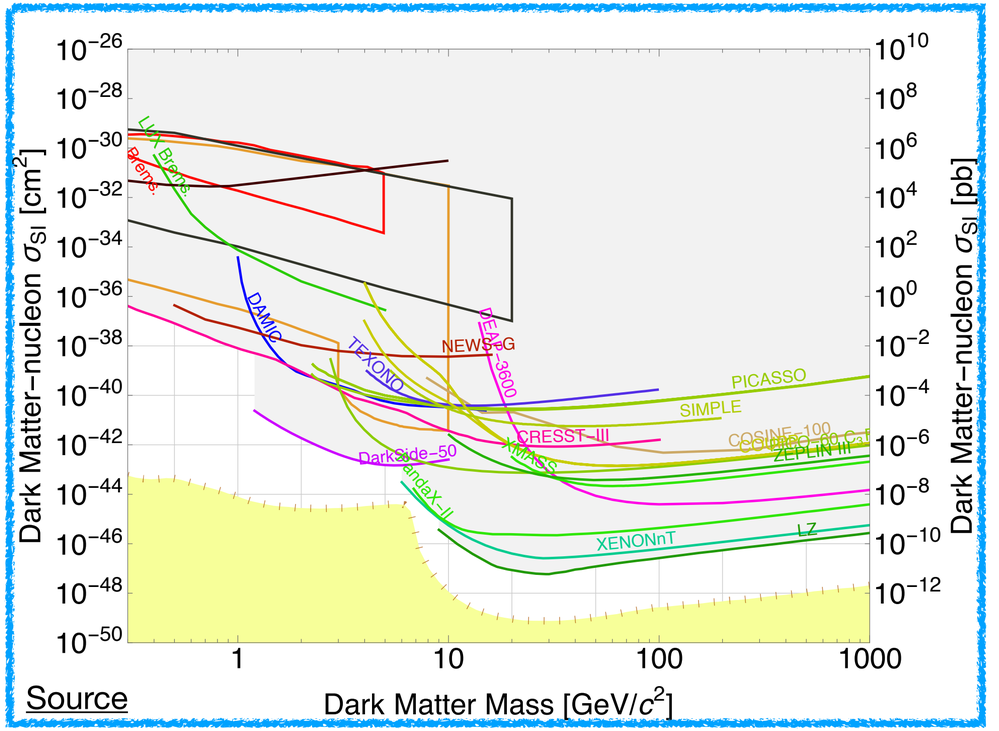


- Weakly interacting massive particles (WIMPs) have been a focus of many past and proposed experiments
- No experimental evidence so far



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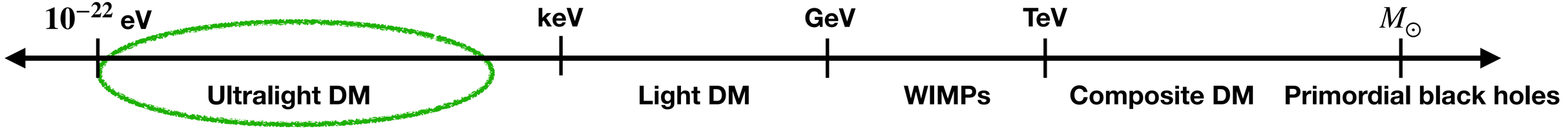
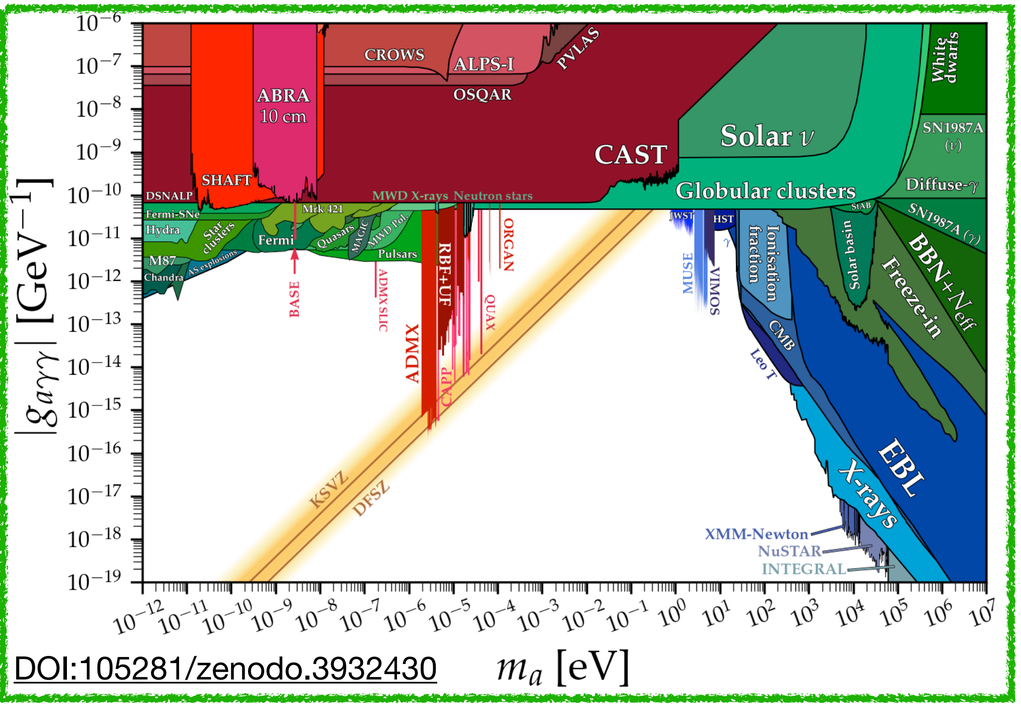
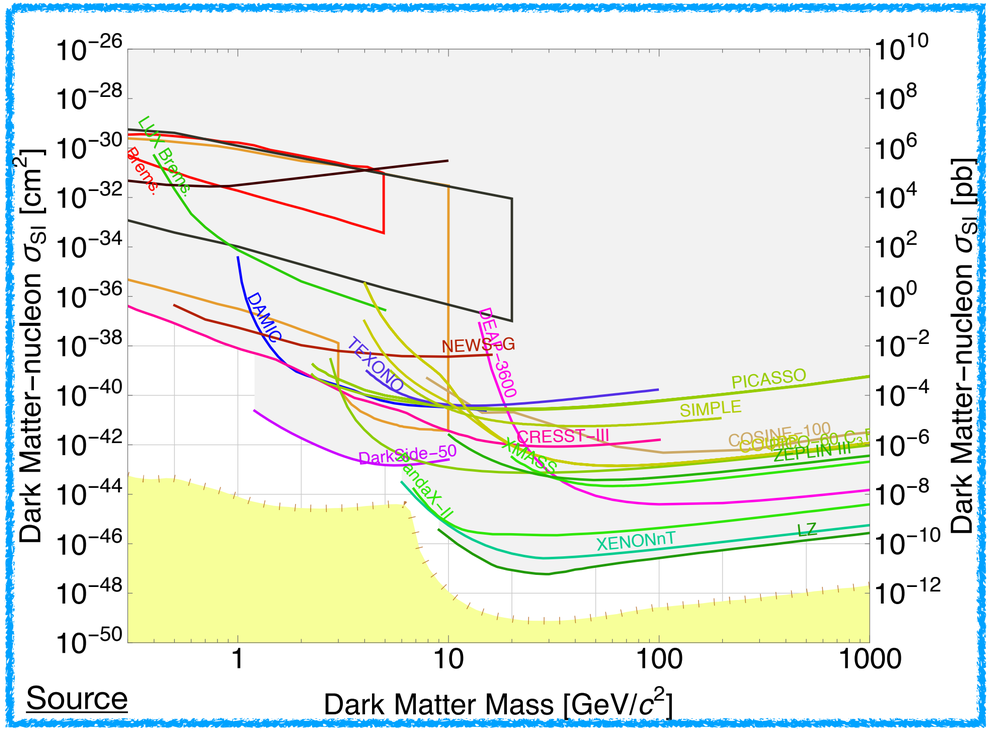




DOI:105281/zenodo.3932430

- Axion searches have also failed to produce any experimental evidence of dark matter



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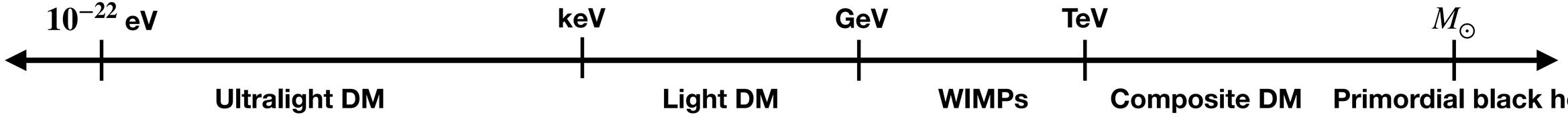
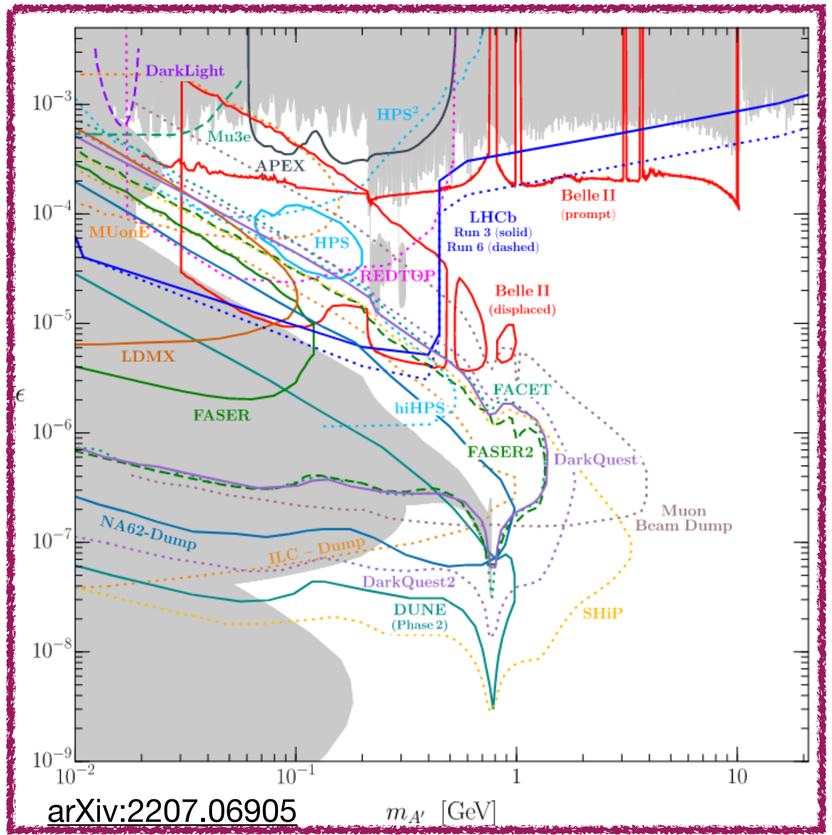




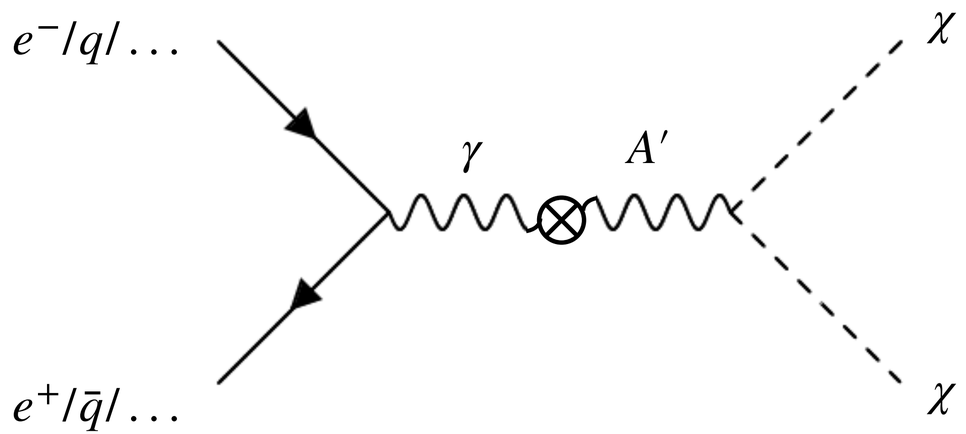
arXiv:2207.06905

- Recently more interest in DM candidates on the MeV scale
- Includes dark sector models

Dark Photon

- Posits a dark sector not charged under an SM gauge group, where interactions with the SM are facilitated by an intermediary particle
- Dark photon implies an additional U(1) gauge group
- Kinetic mixing with the SM photon

$$\mathscr{L}_{\text{int}} = e\varepsilon J_\mu A'^\mu$$



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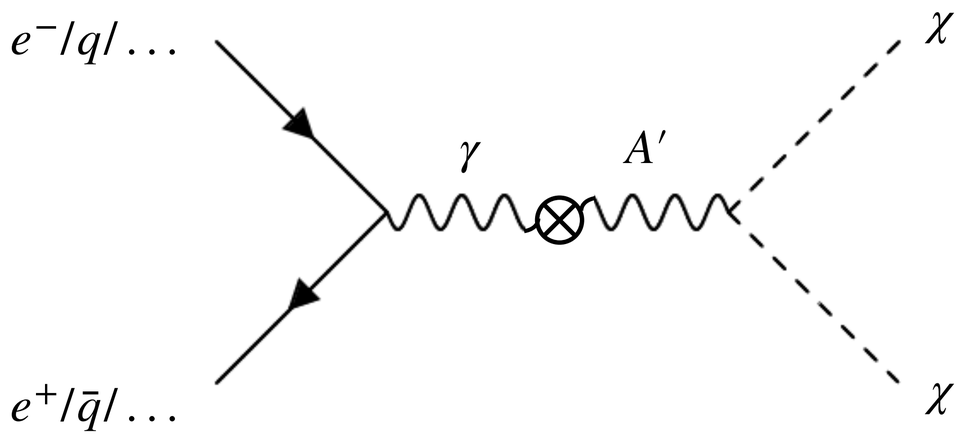

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Dark photon

Kinetic mixing strength

SM QED current

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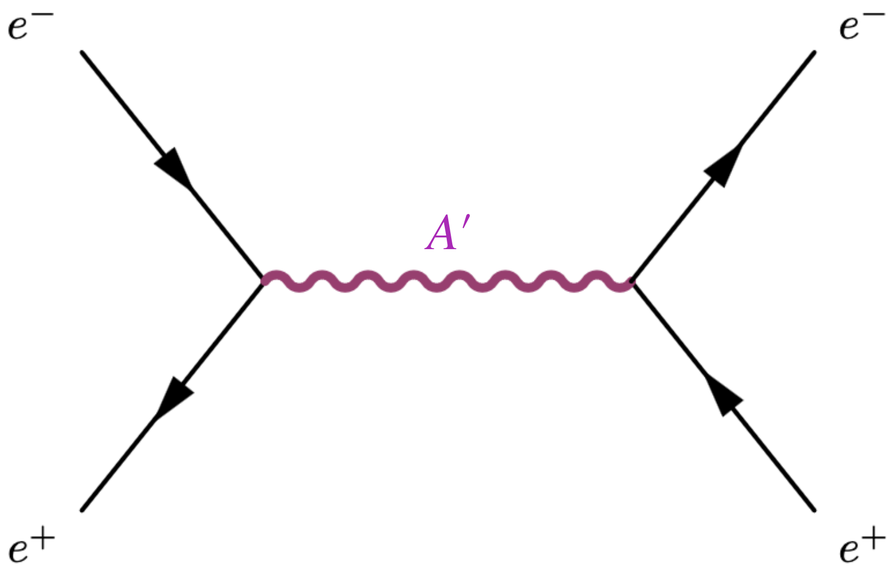

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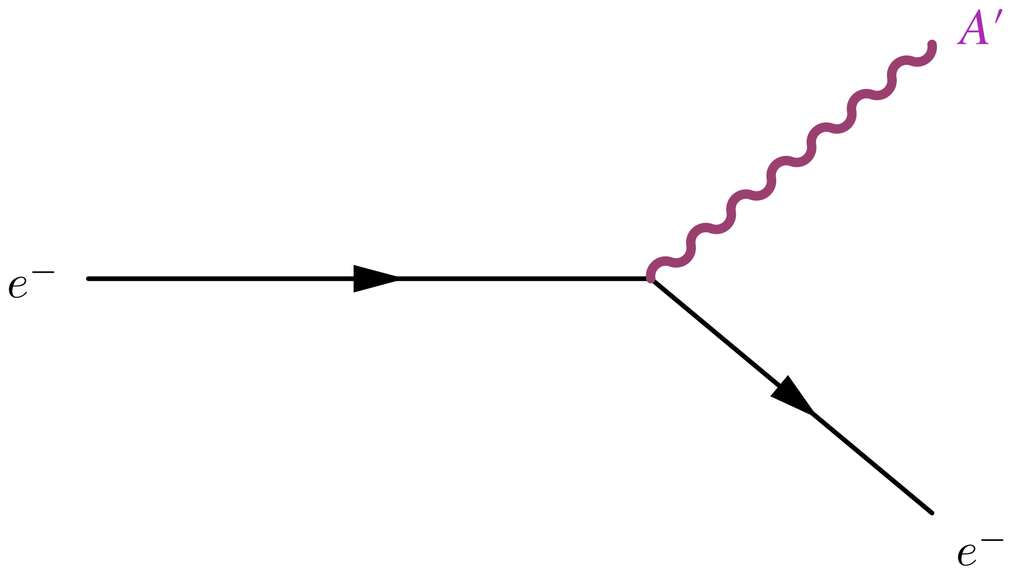

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Experimental Anomalies: $g_\mu - 2$

- Anomalous magnetic moment of the muon measured very precisely by the Muon g-2 experiment at FermiLab

Latest result: Phys. Rev. Lett. 131, 161802 (2023)

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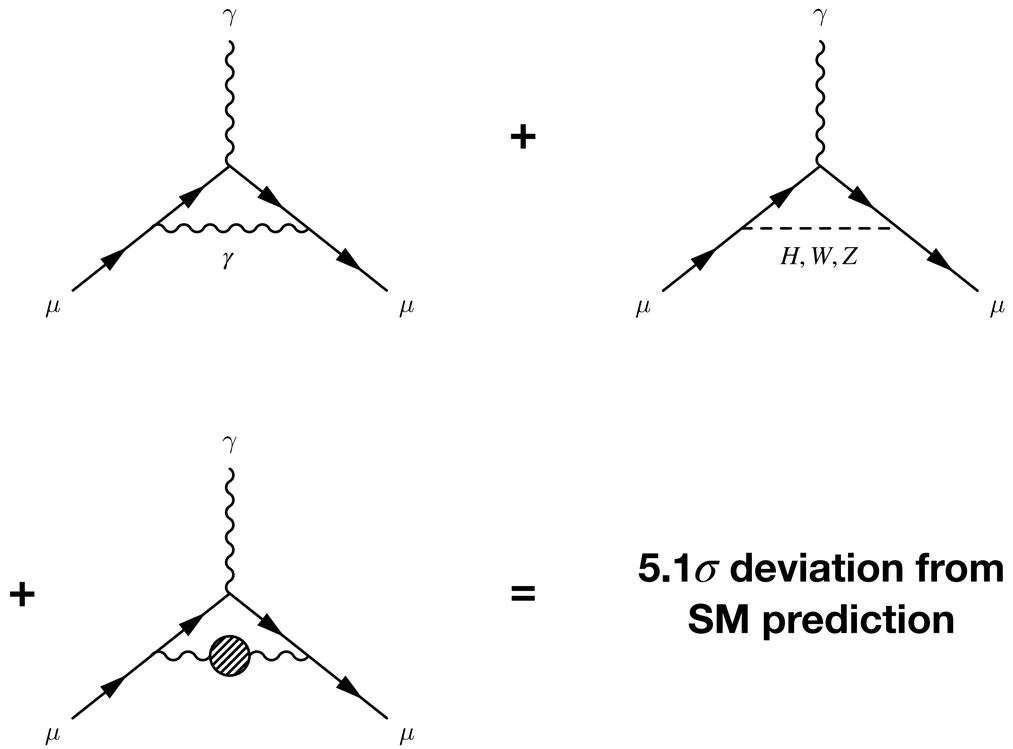

5.1σ deviation from SM prediction

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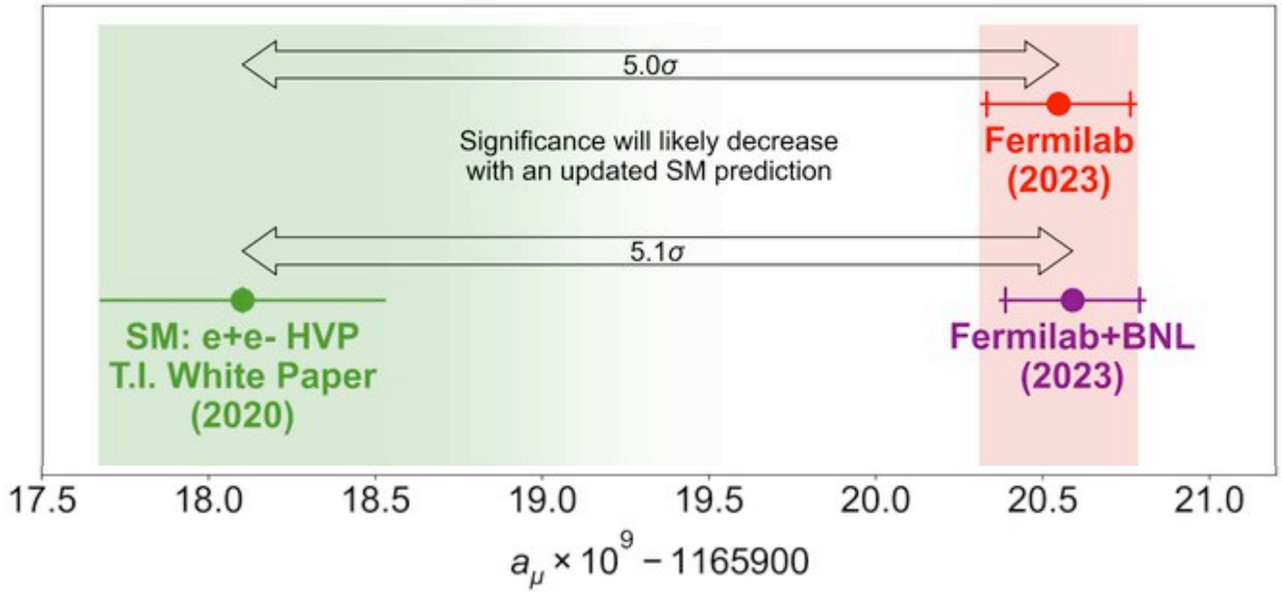

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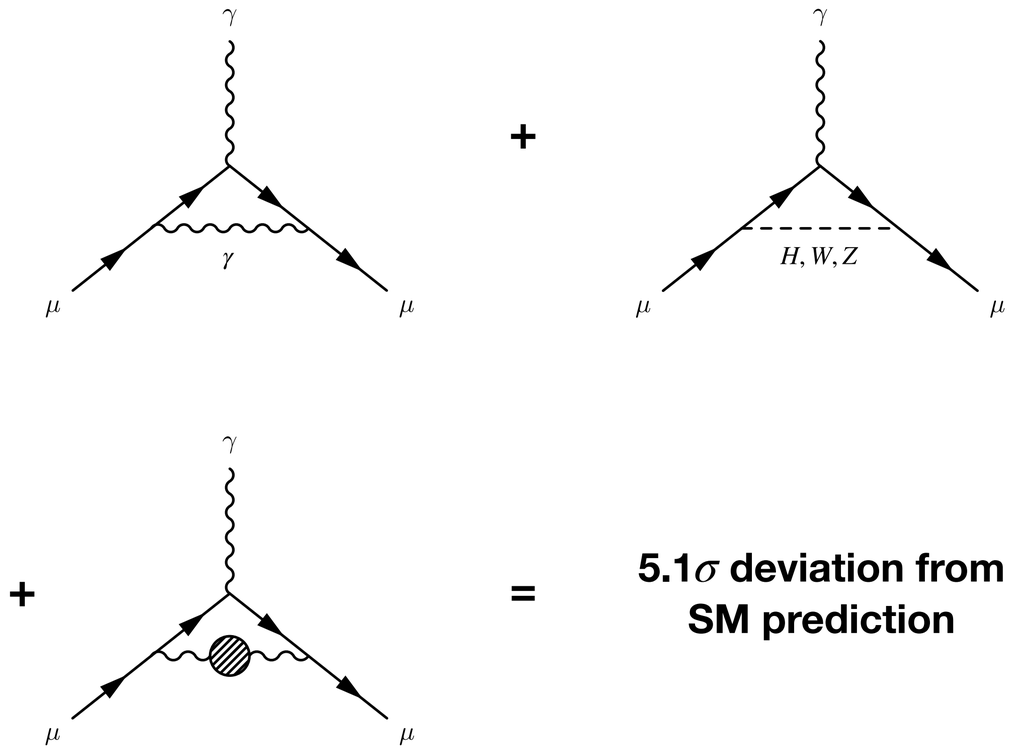

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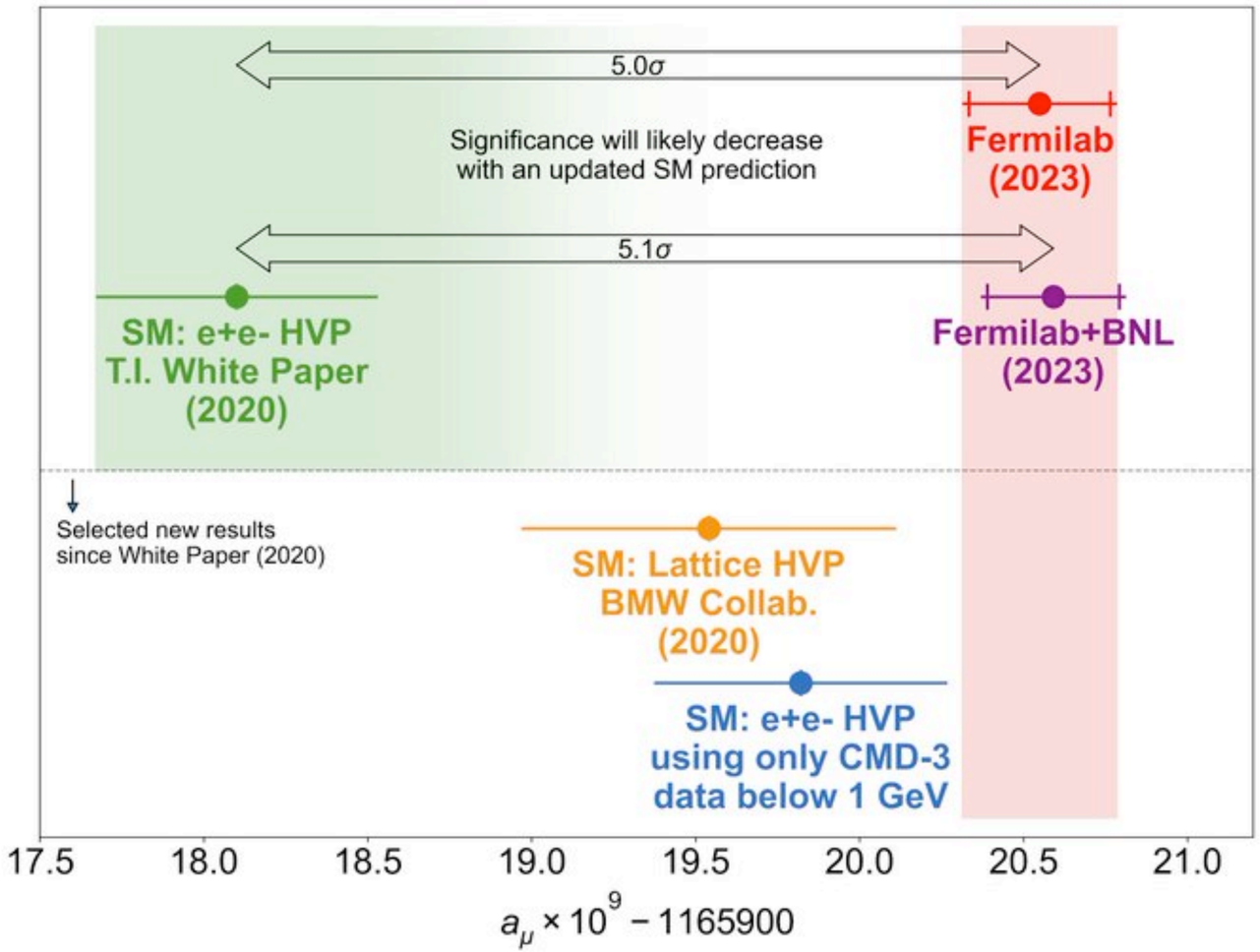

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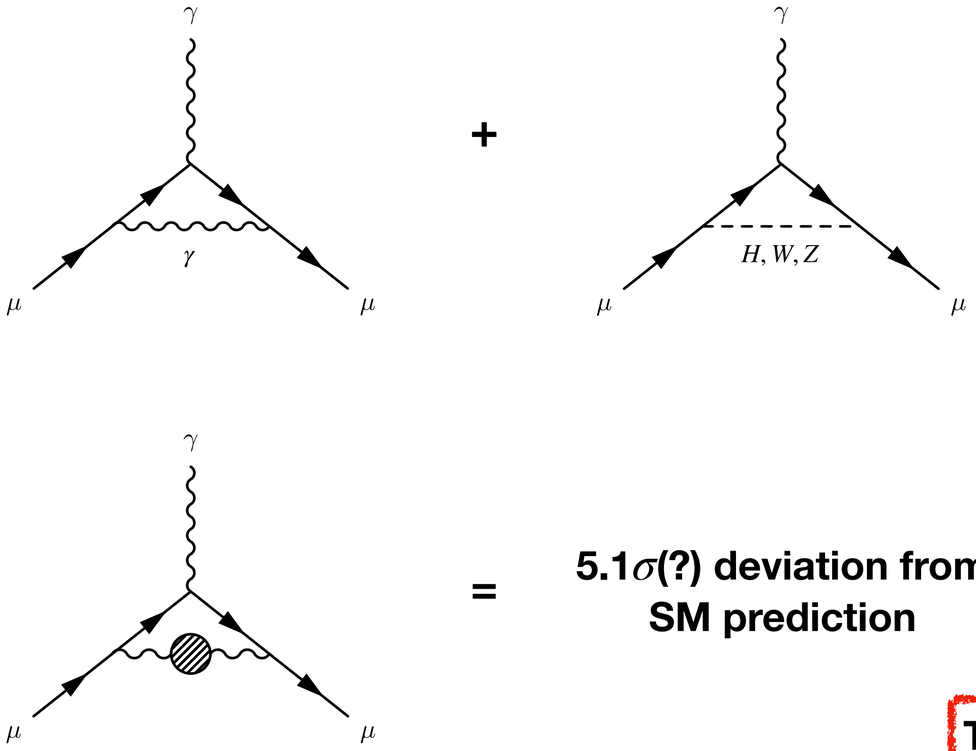

5.1σ(?) deviation from SM prediction

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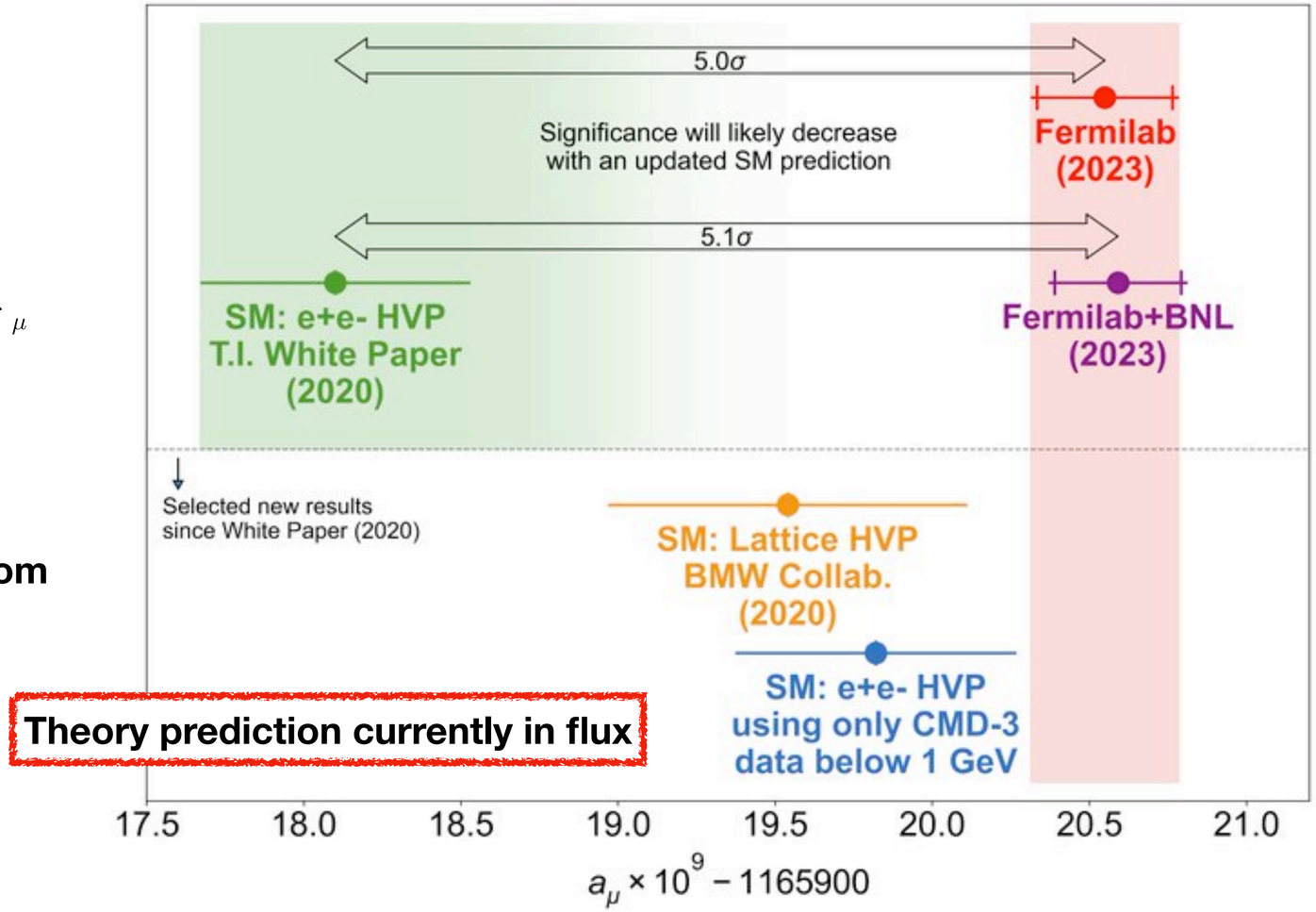

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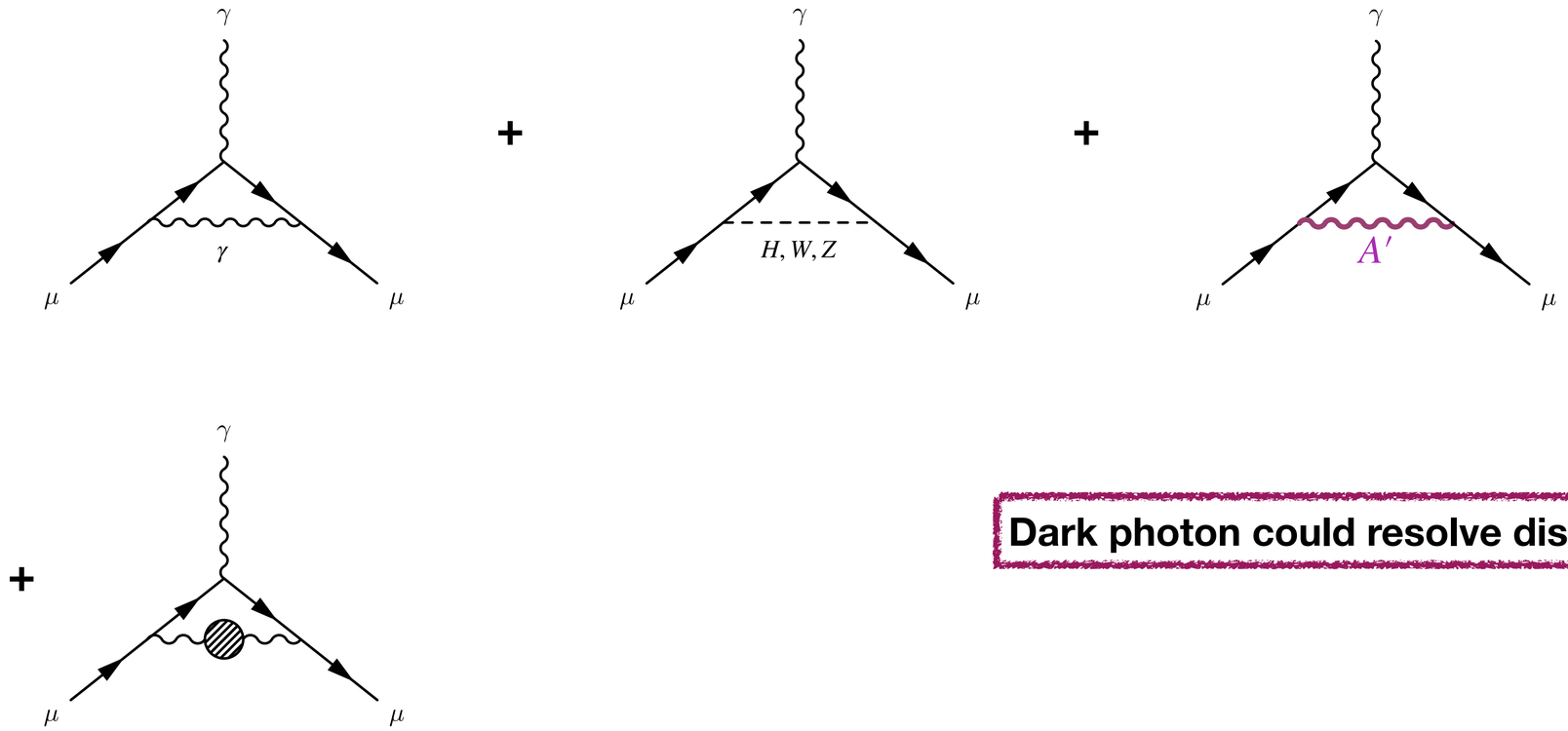

Dark photon could resolve discrepancy

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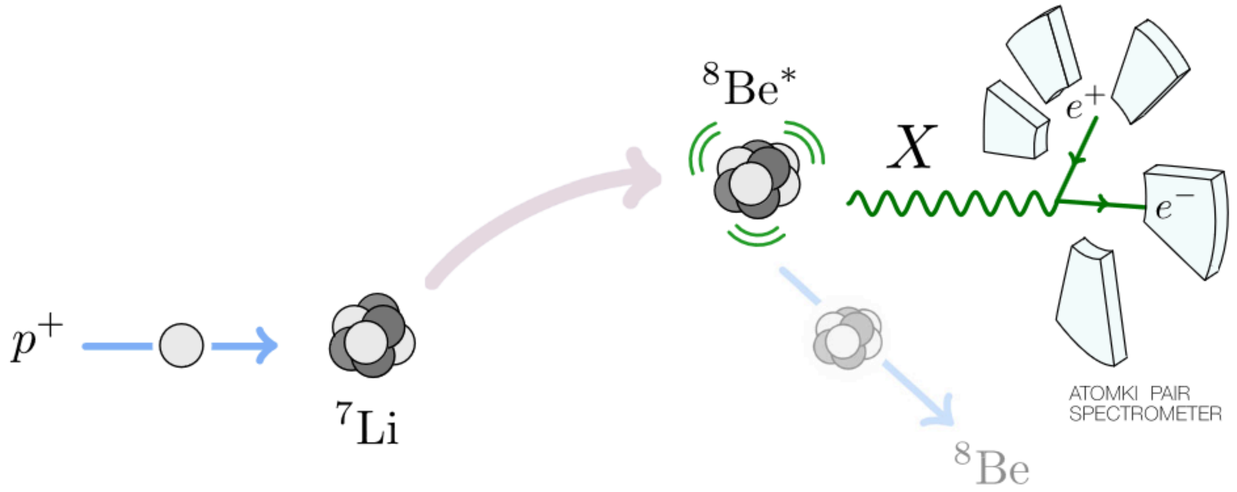
Experimental Anomalies: X17

- Originally observed by ATOMKI collaboration in excited state decays of ^{8}Be



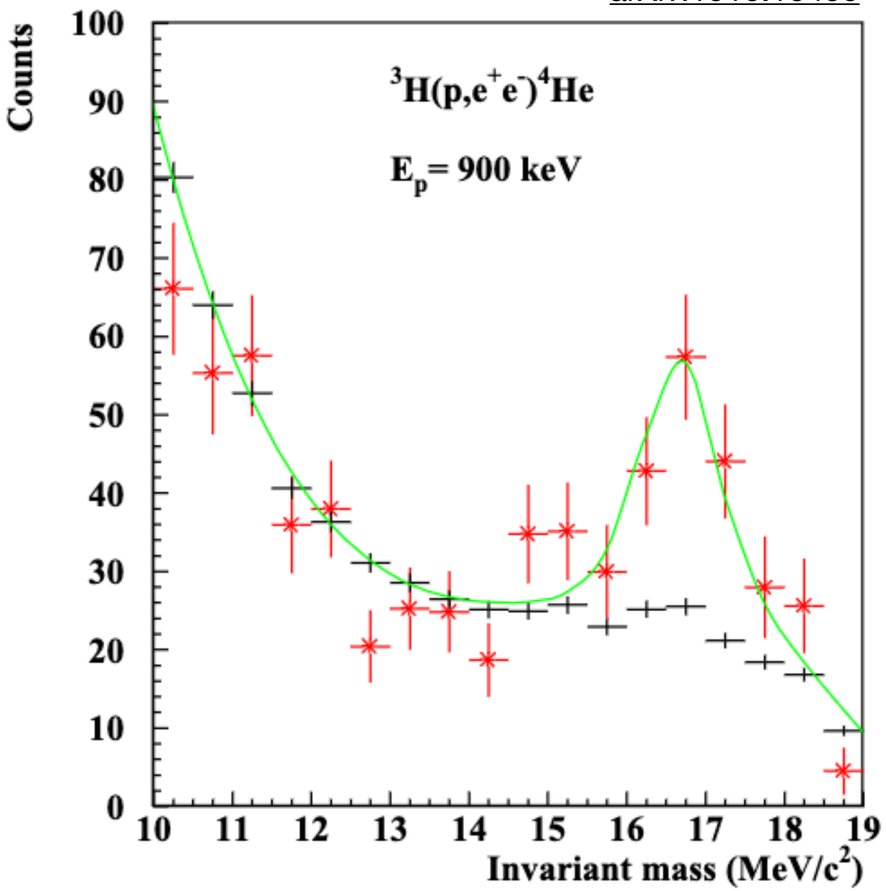
Physical Review D 95, 035017 (2017)

See: Phys. Rev. Lett. 116, 042501 (2016), arXiv:1910.10459, Phys. Rev. C 104, 044003 (2021), arXiv:2205.07744, Phys. Rev. C 106, L061601 (2022), arXiv:2308.06473, arXiv:2401.11676

Experimental Anomalies: X17

- Originally observed by ATOMKI collaboration in excited state decays of ^{8}Be
- Excess in e^+e^- invariant mass spectrum possibly indicative of a new boson with mass around 17 MeV
- Similar anomaly observed in ^{4}He, ^{12}C and using an independent apparatus
- Other ongoing efforts to confirm this

arXiv:1910.10459



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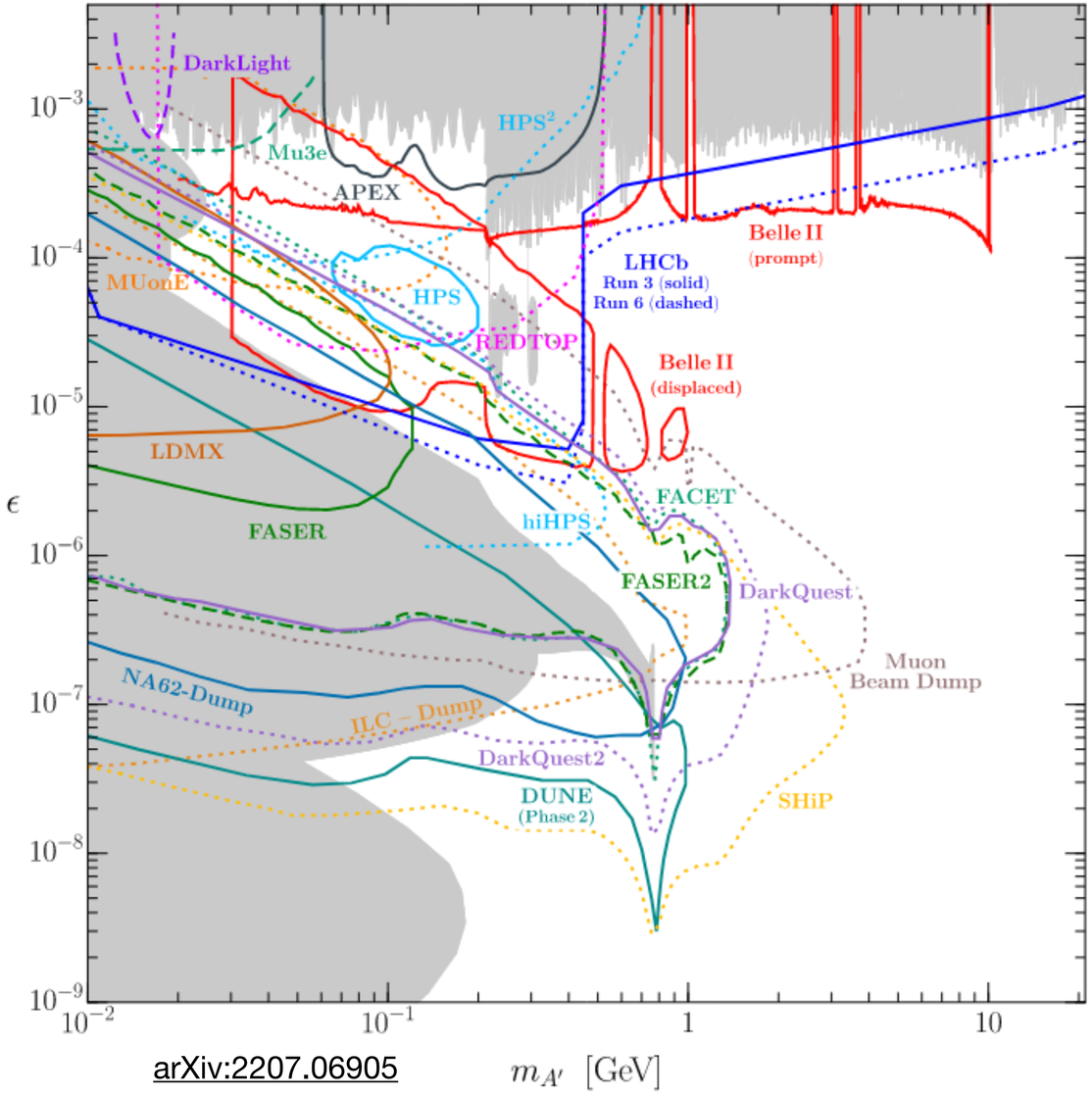
Dark Photon: Current Limits

Limits for past (grey) and future dark photon experiments



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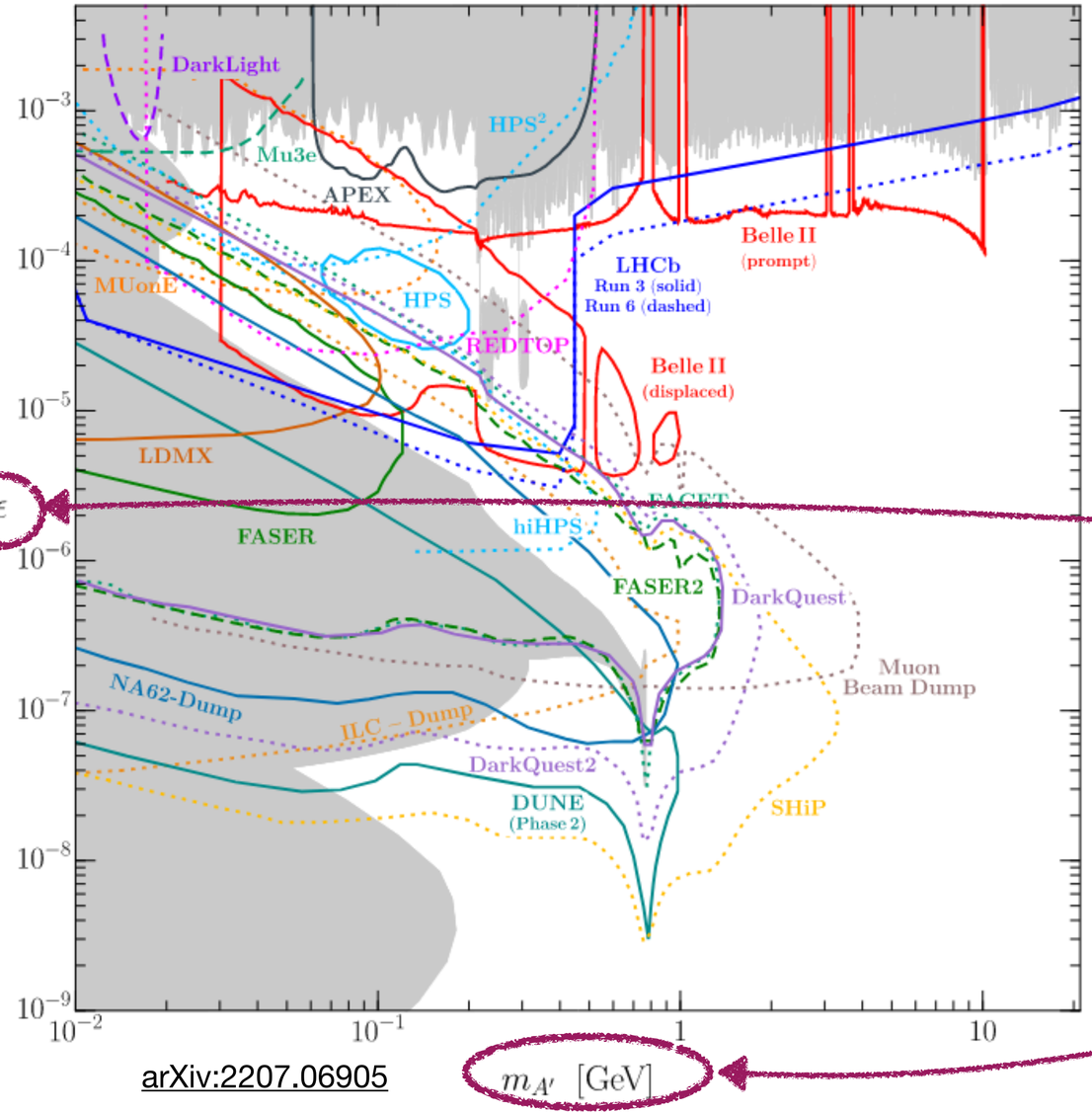

Kinetic mixing strength

Dark photon mass

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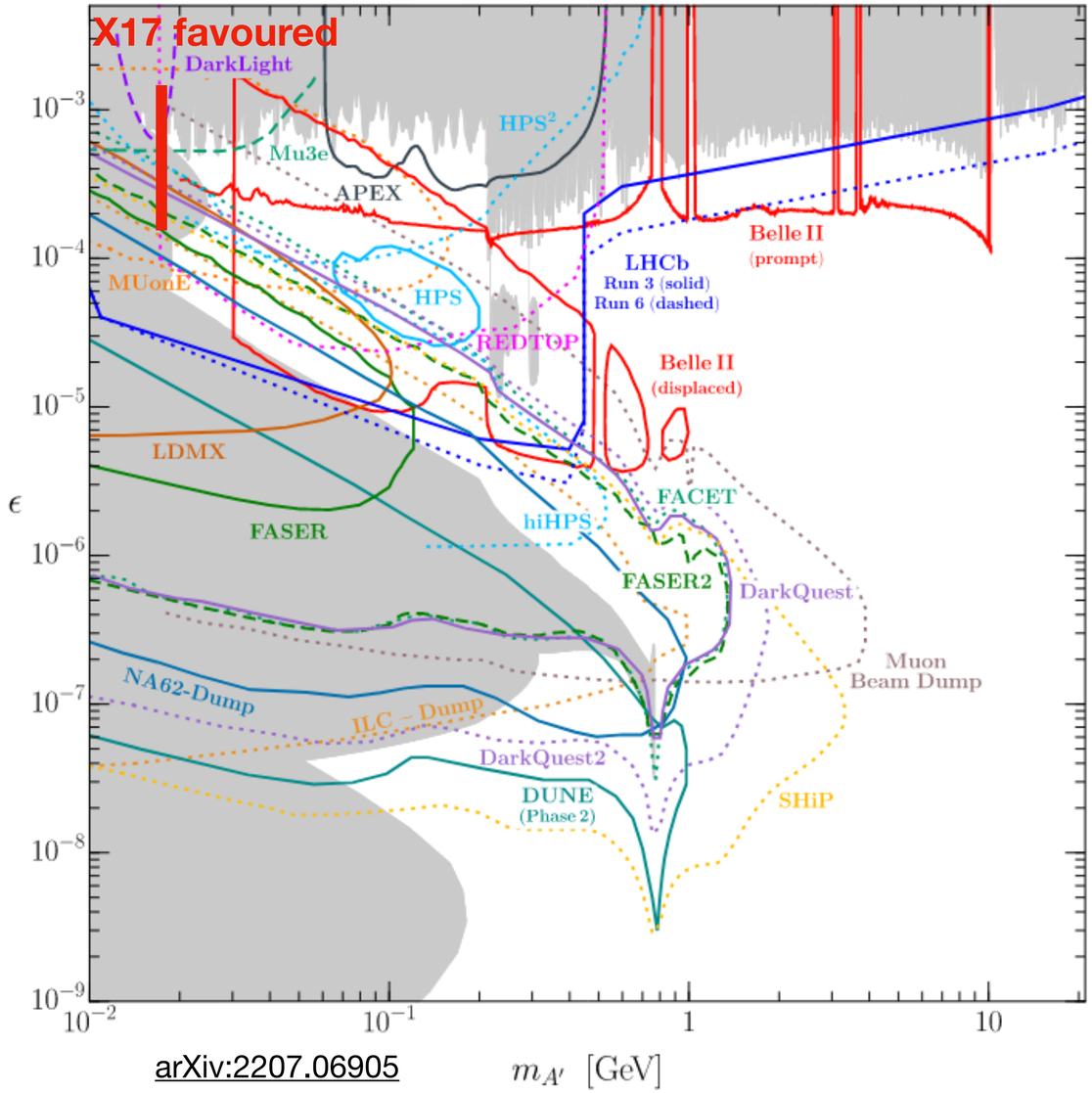

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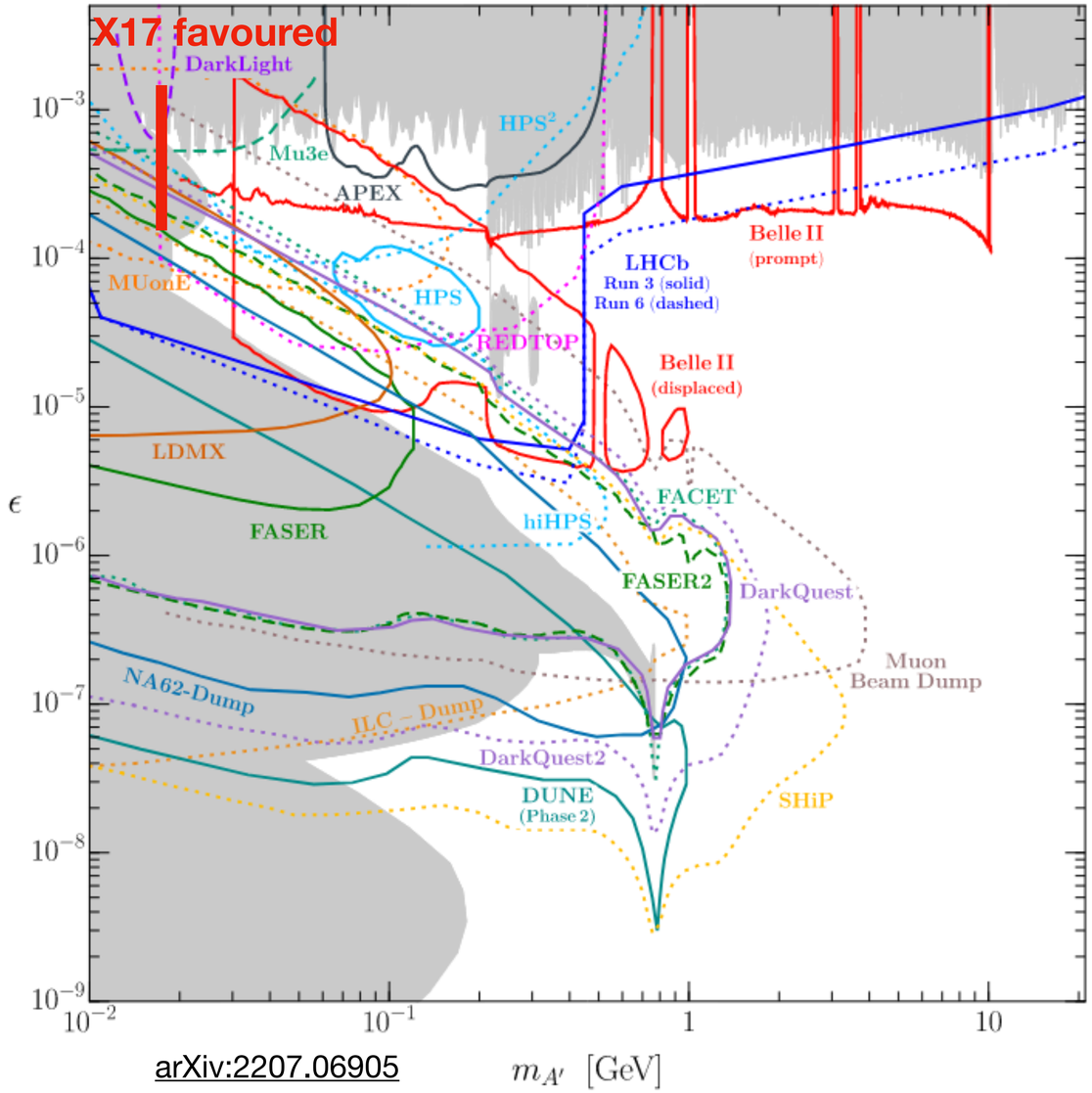

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- Unclear exactly what form the coupling ε takes
- **Protophobic** coupling (reduced coupling to protons) required by the X17
  - Coupling no longer universal to the EM current: $\mathscr{L}_{\text{int}} = e\varepsilon J_\mu A'^\mu$
  - Instead something more complex, but can still display limits in the same parameter space

For more details see: Feng et. al. PRL 117, 071803 (2016), Physical Review D 95, 035017 (2017), Physical Review D 102, 036016 (2020)

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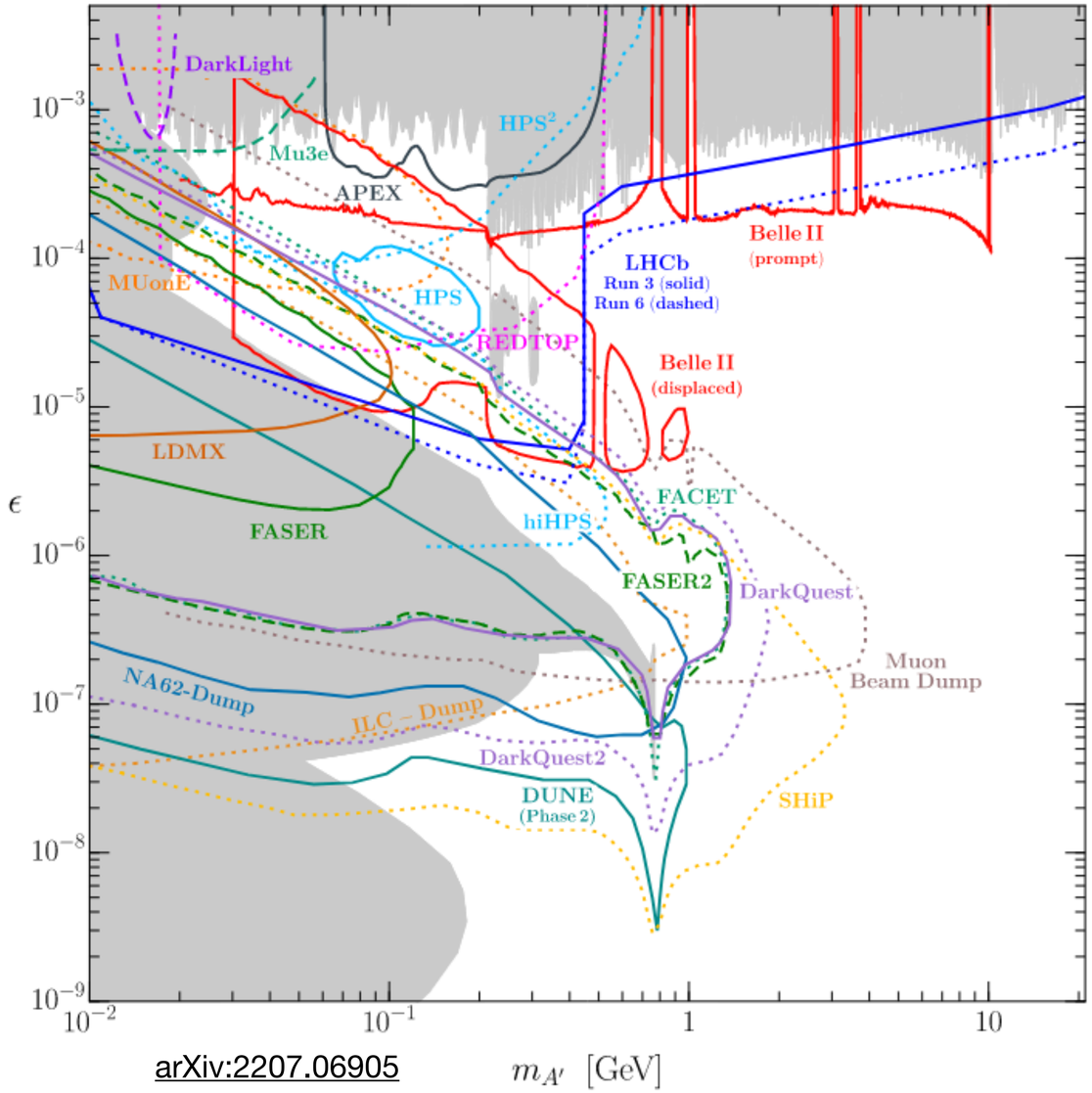

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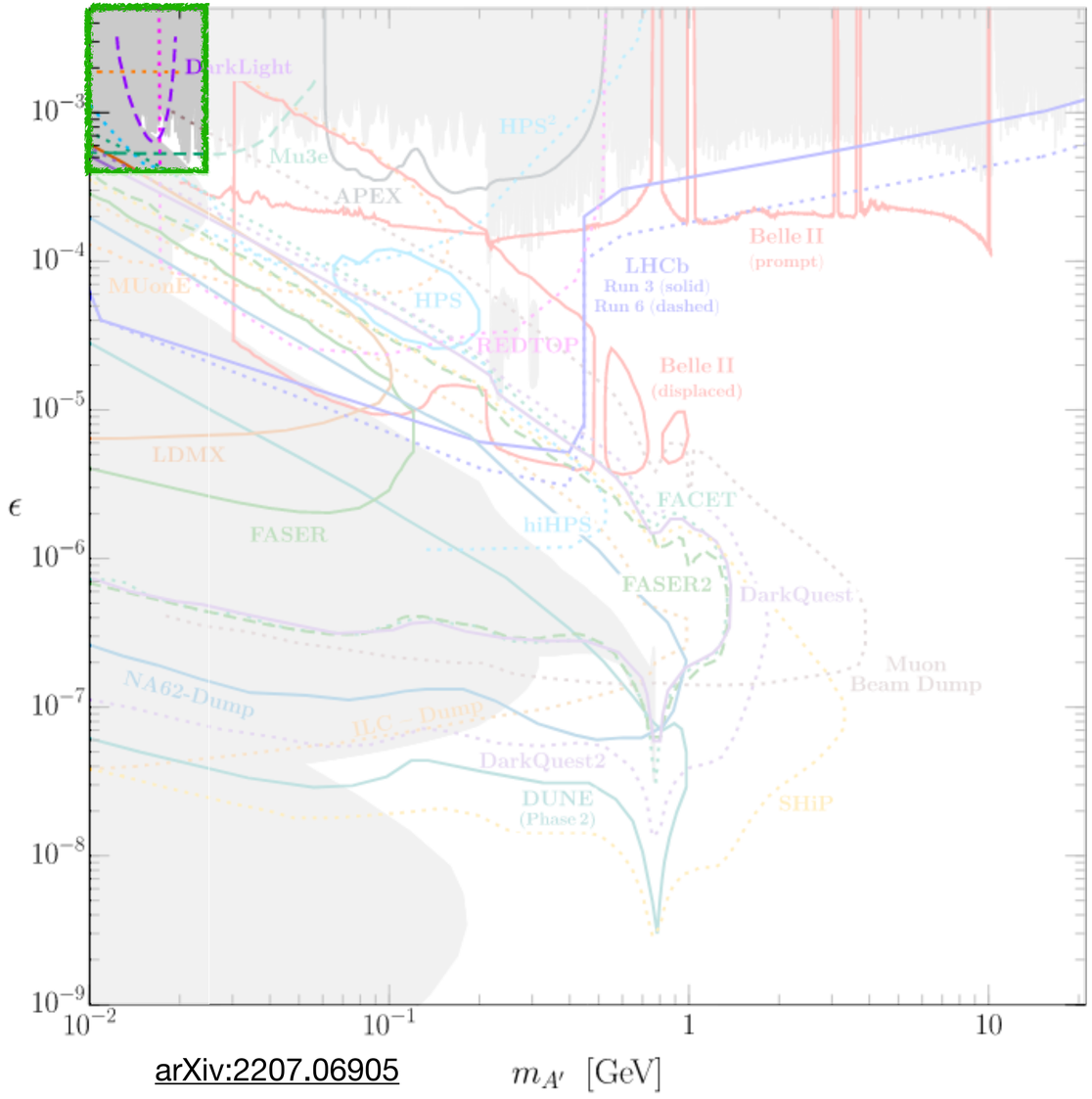

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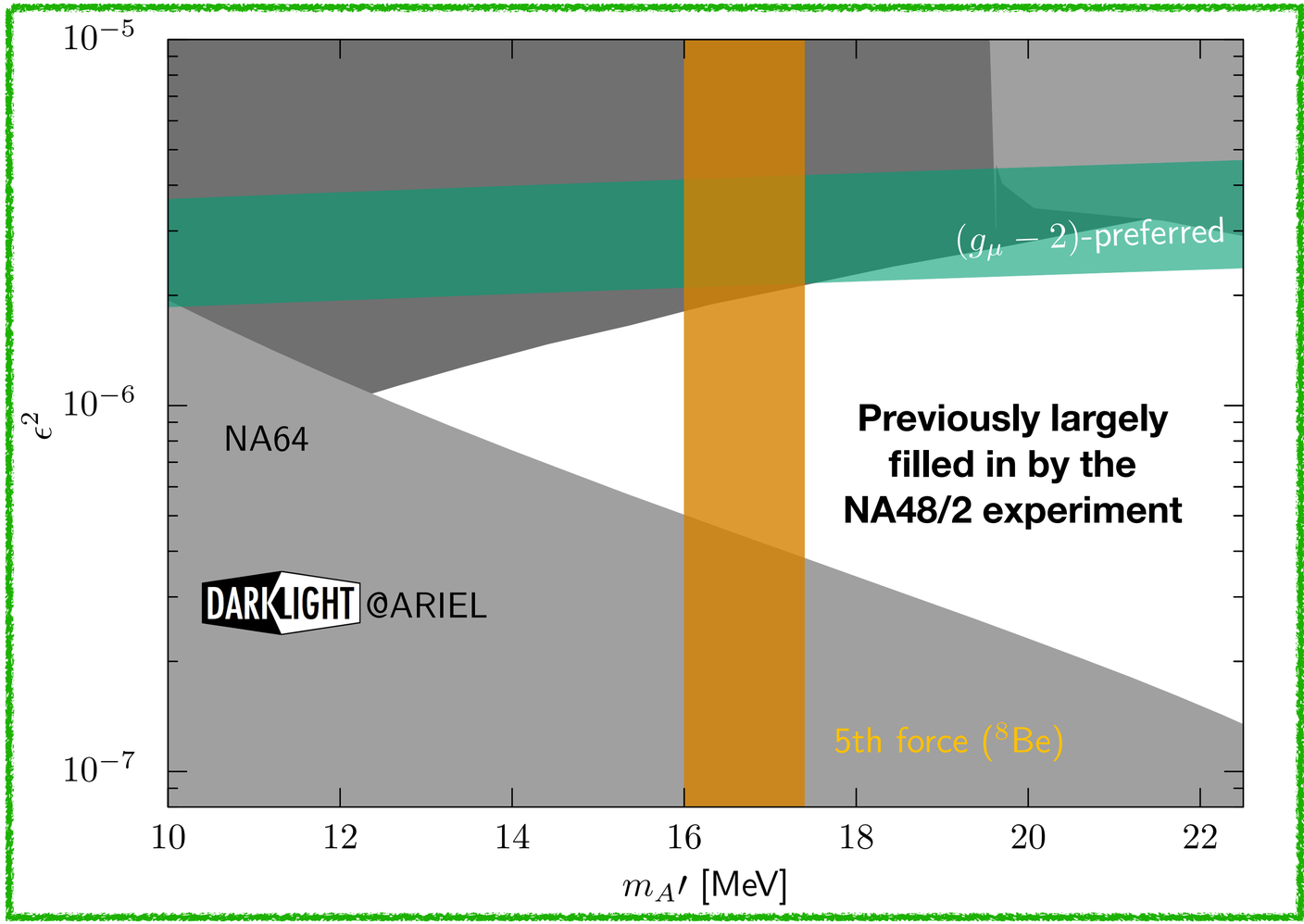

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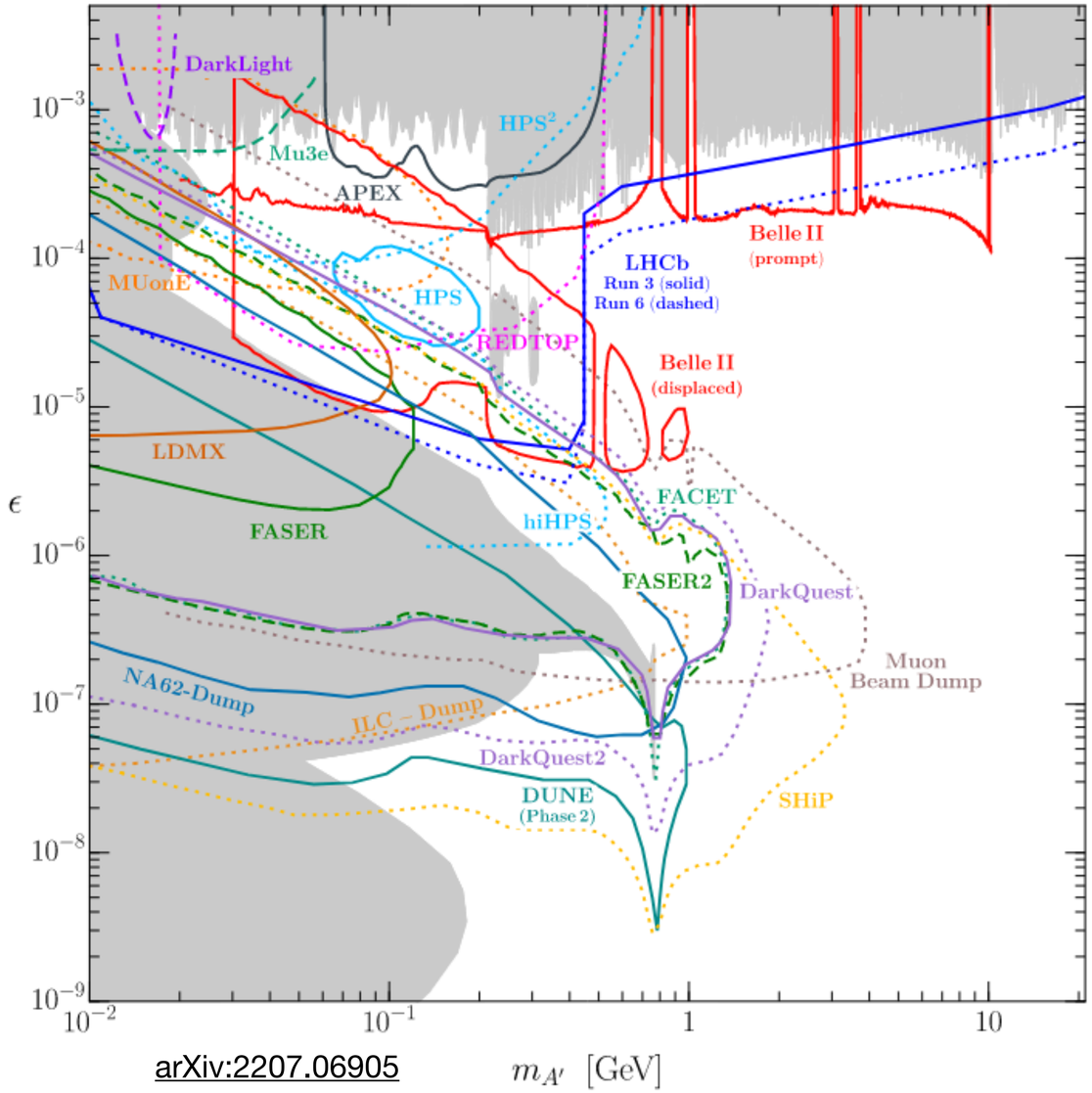

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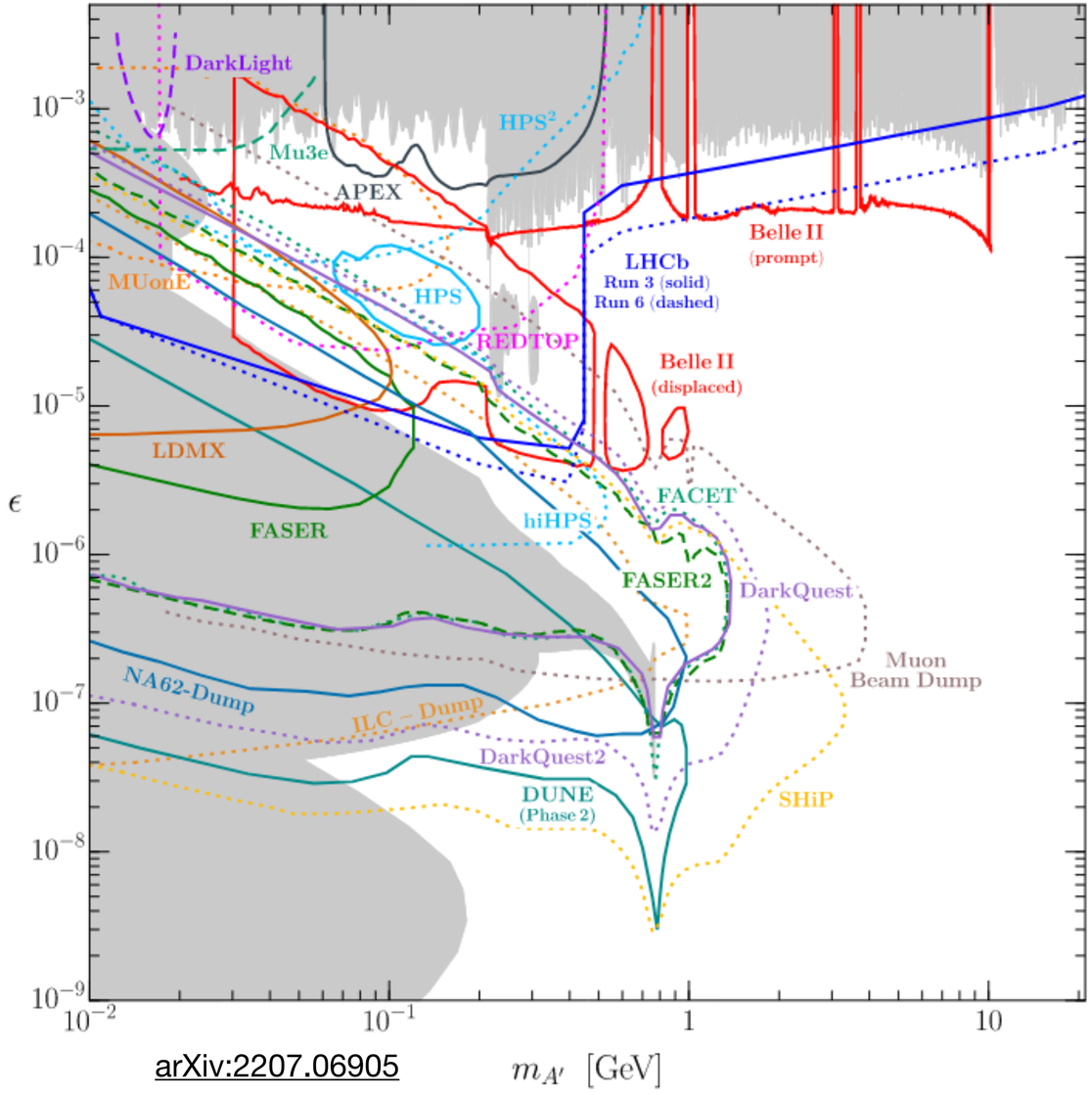

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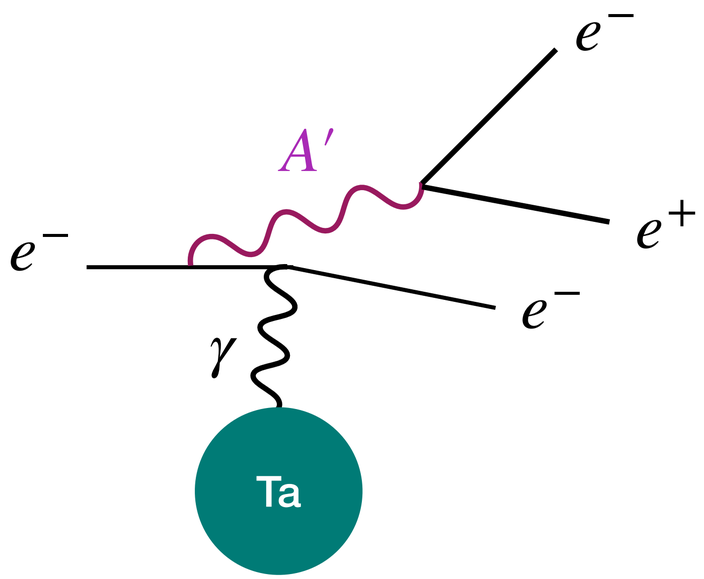

DarkLight@ARIEL

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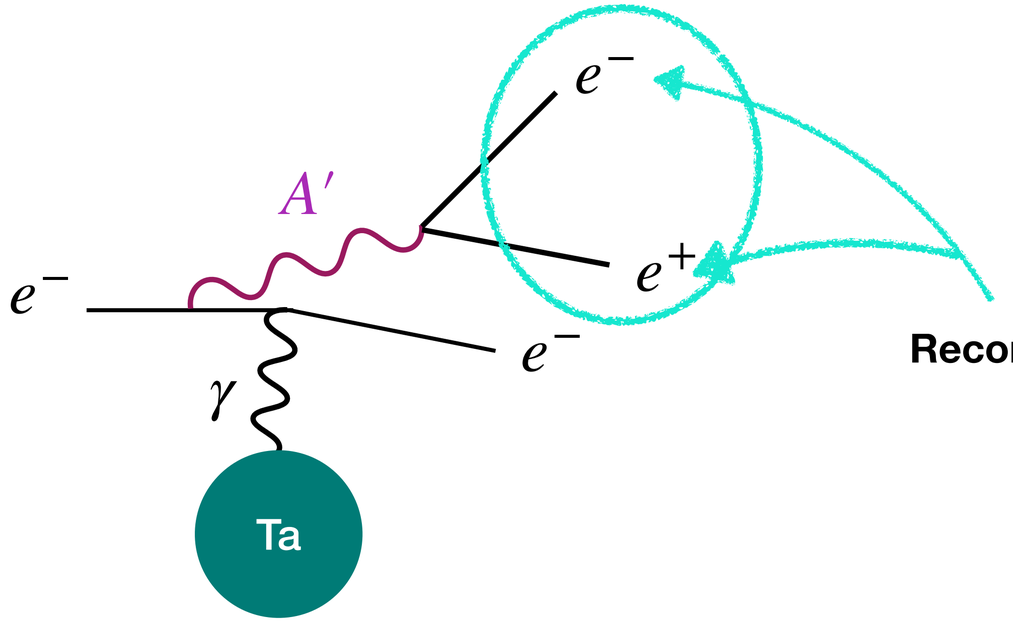

Reconstruct invariant mass of electron-positron system

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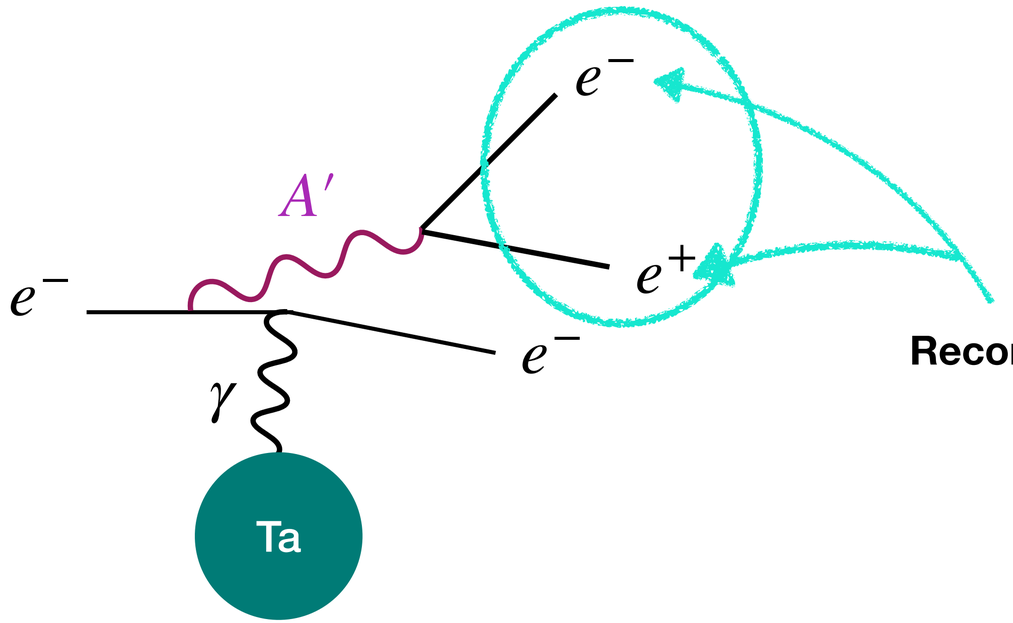
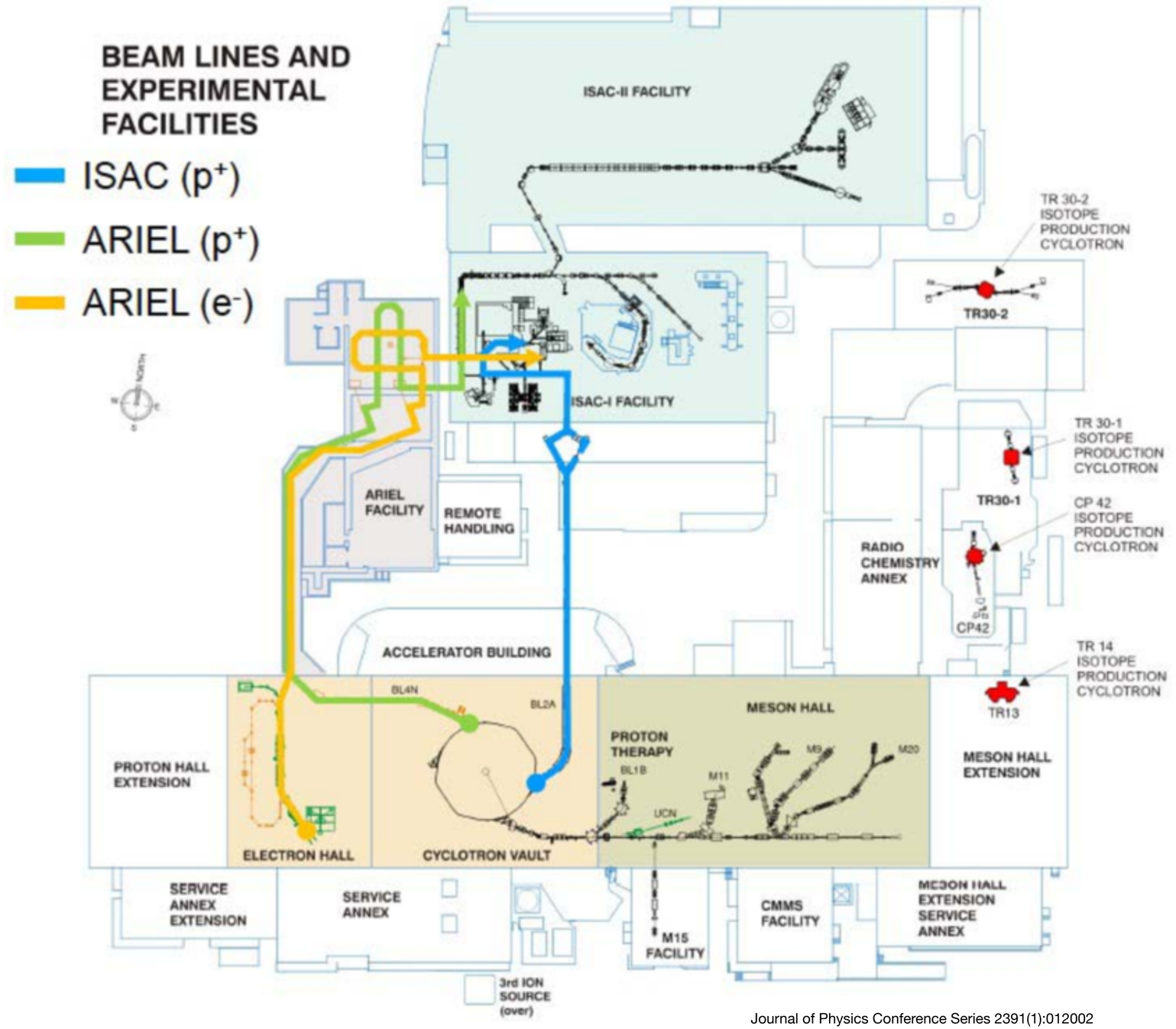


Reconstruct invariant mass of electron-positron system

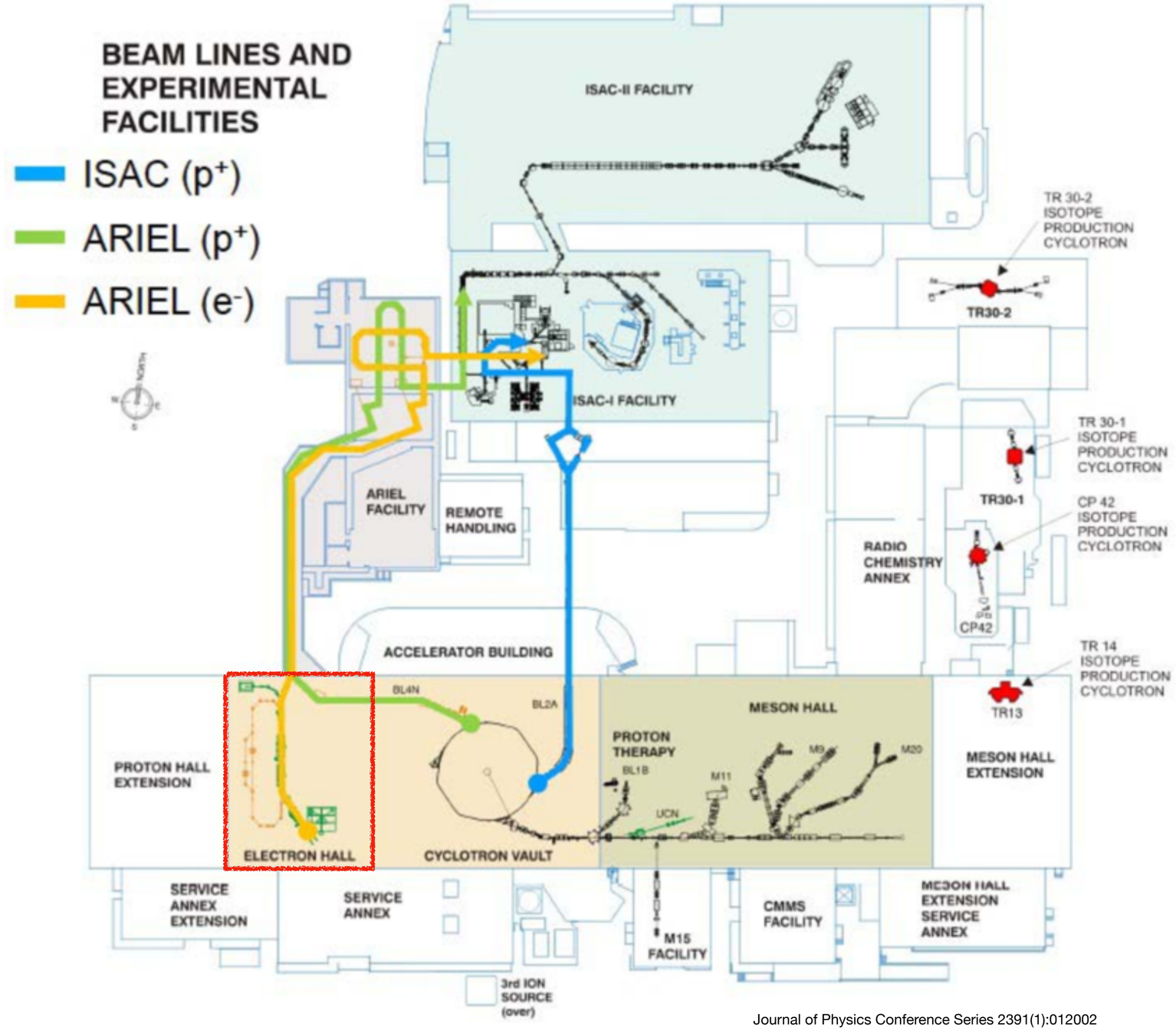
- Low energy allows probe of $g_\mu - 2$ favoured and X17 region, high intensity for lots of statistics

ARIEL



Journal of Physics Conference Series 2391(1):012002

ARIEL



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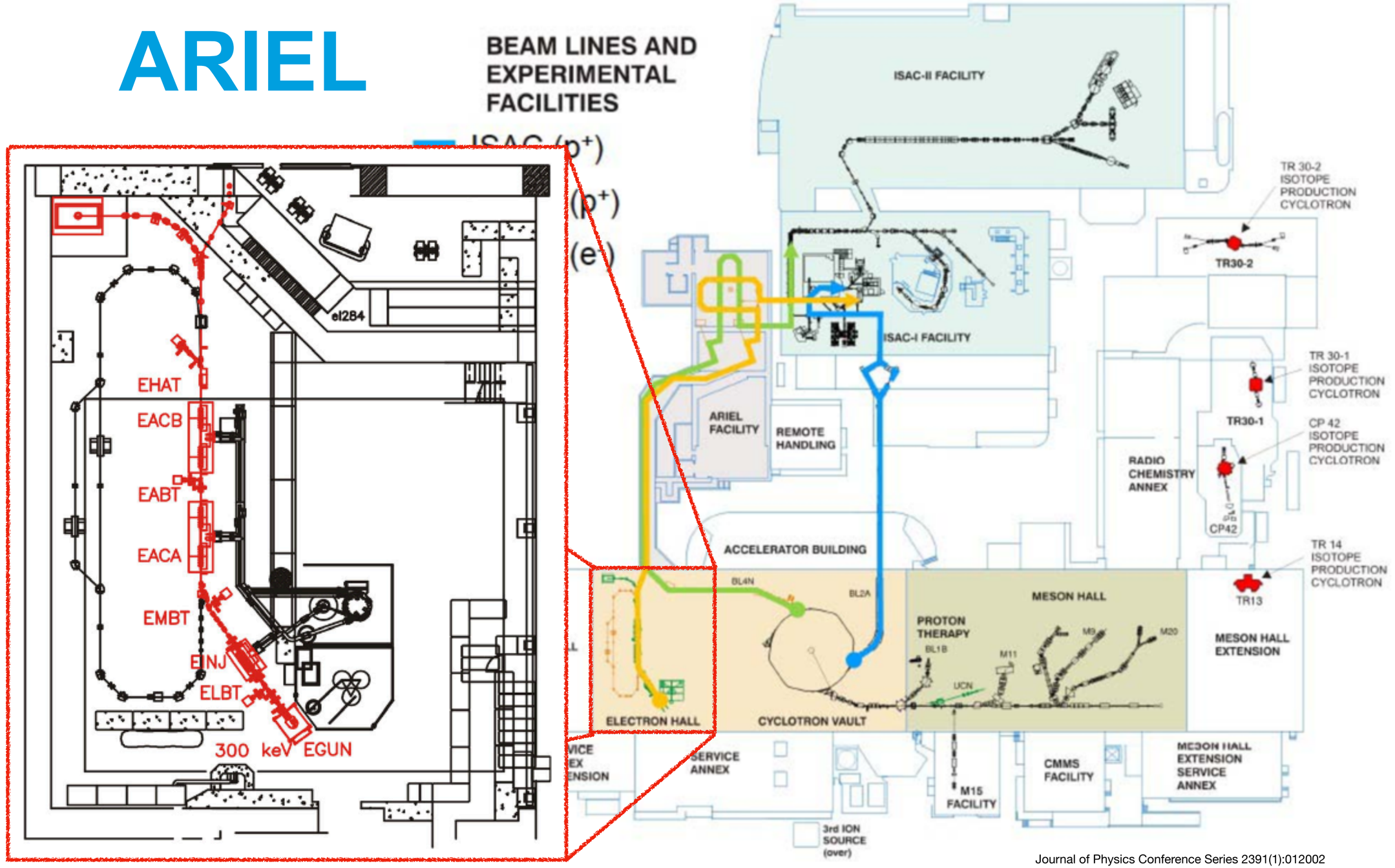
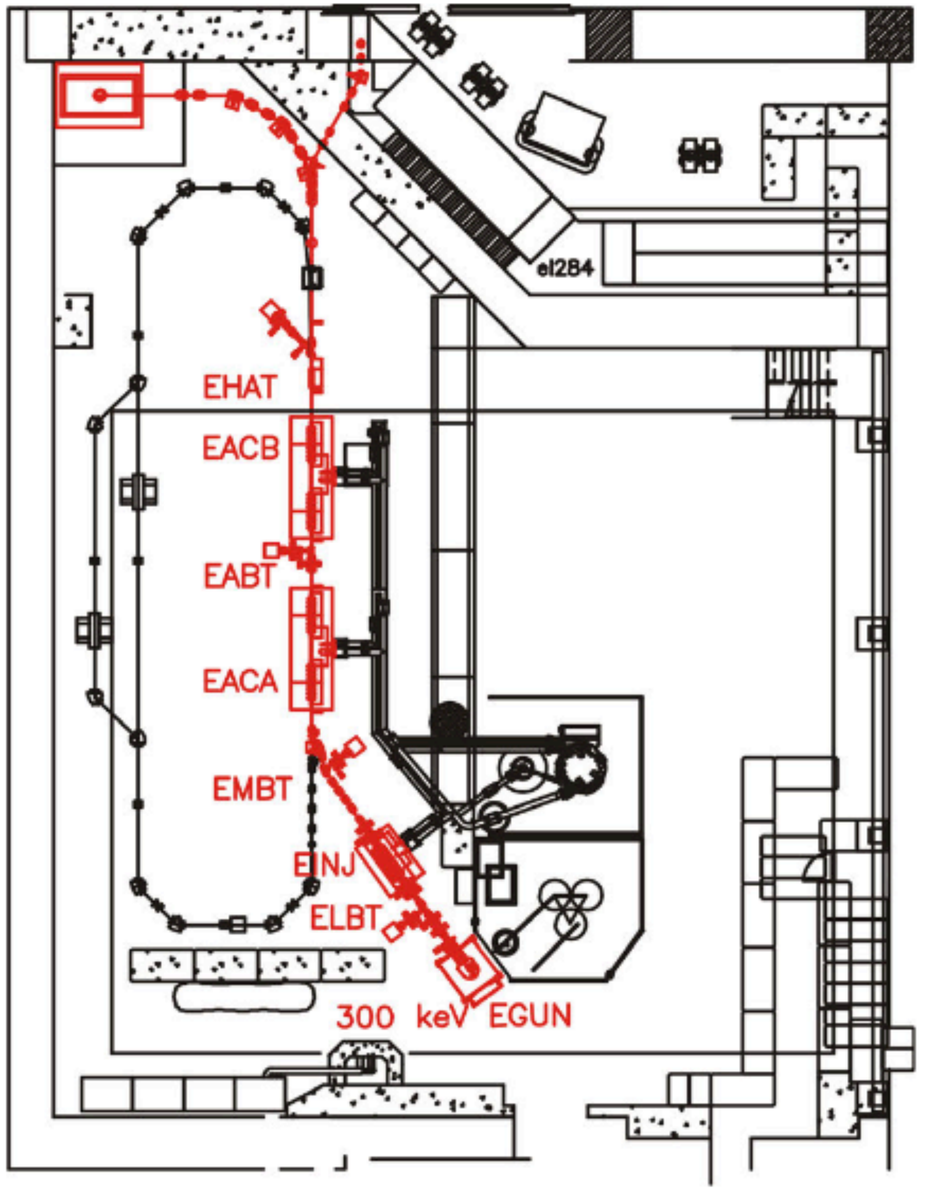


Journal of Physics Conference Series 2391(1):012002

ARIEL e-linac

- 30 MeV electron beam setup



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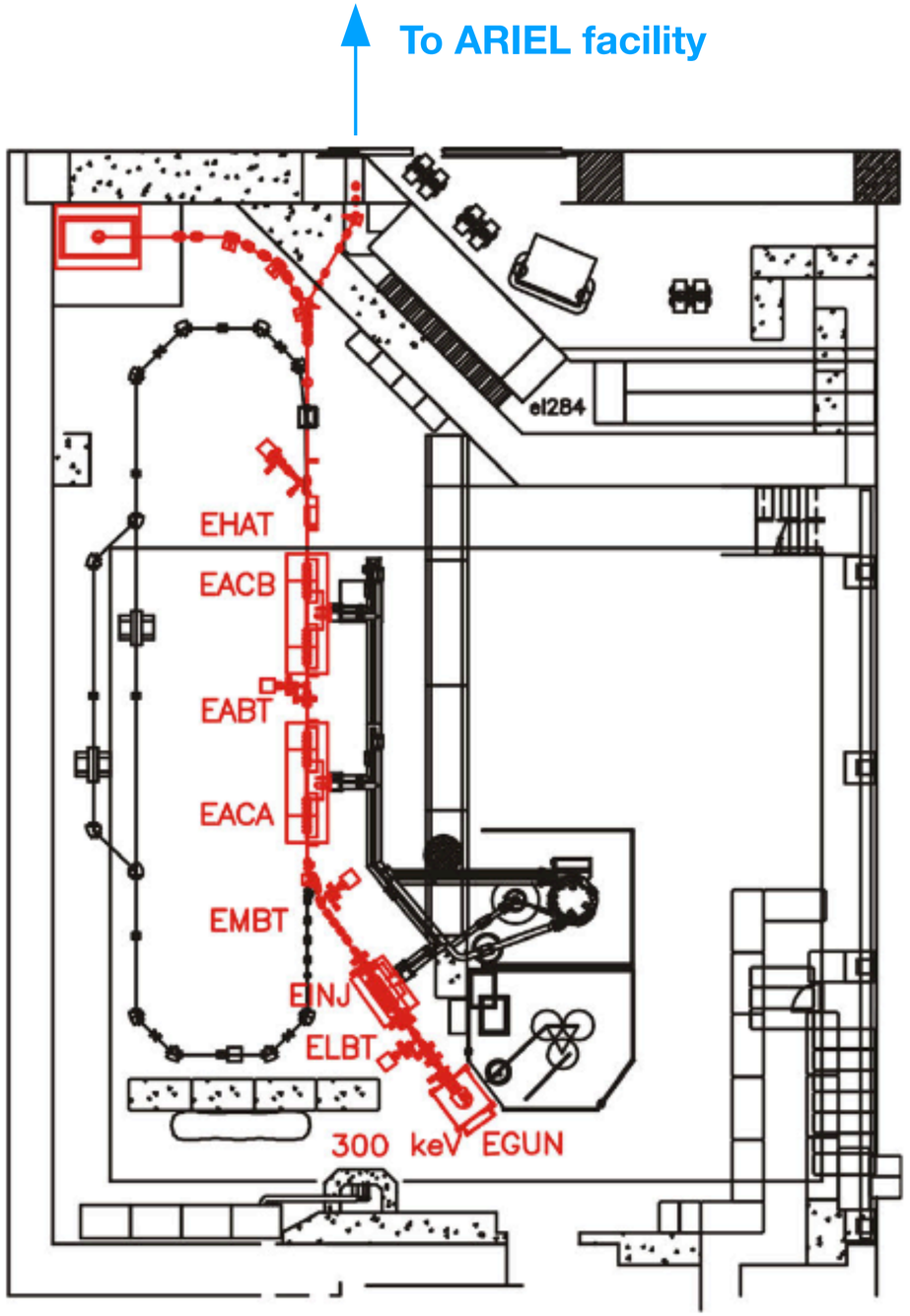

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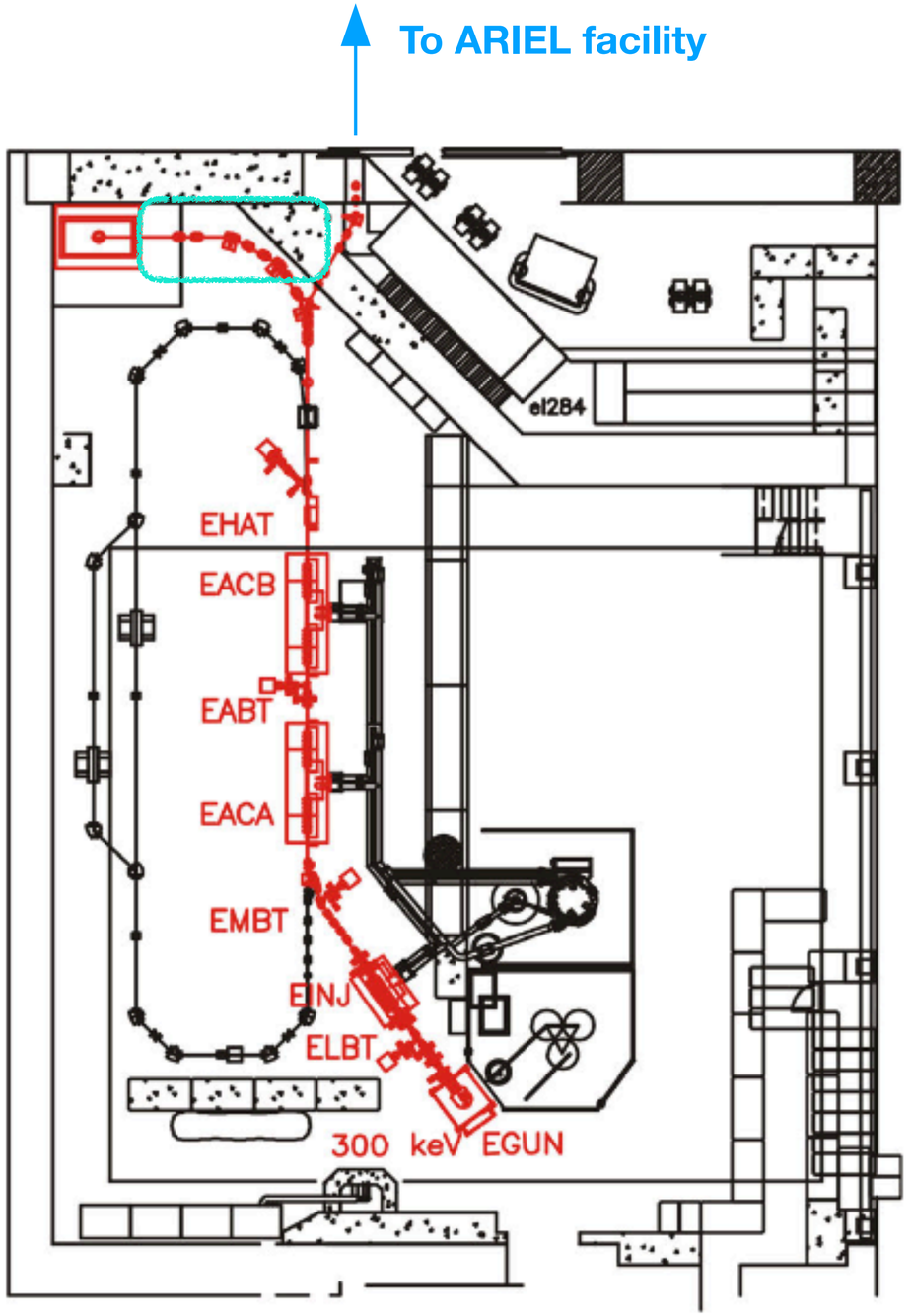

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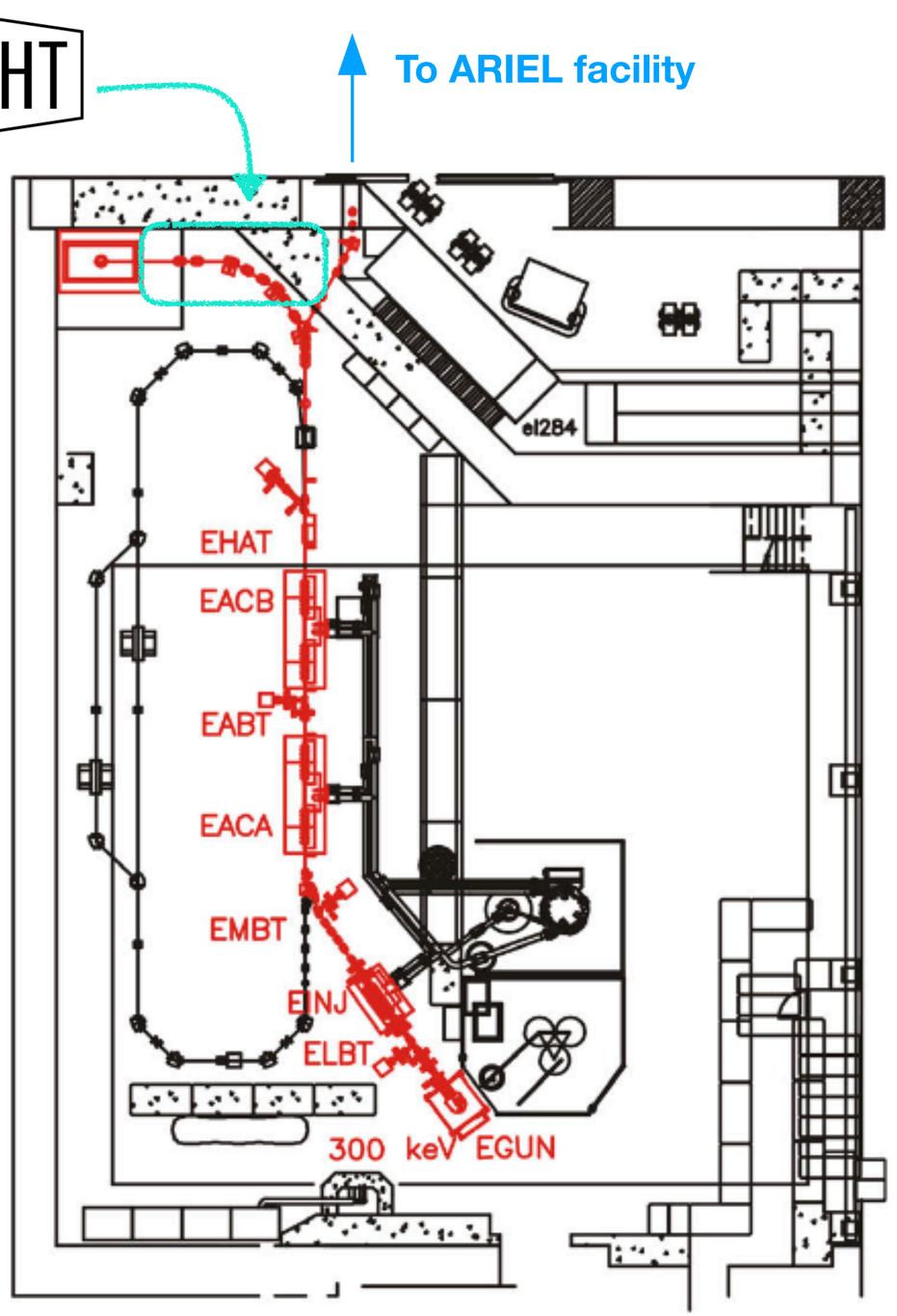

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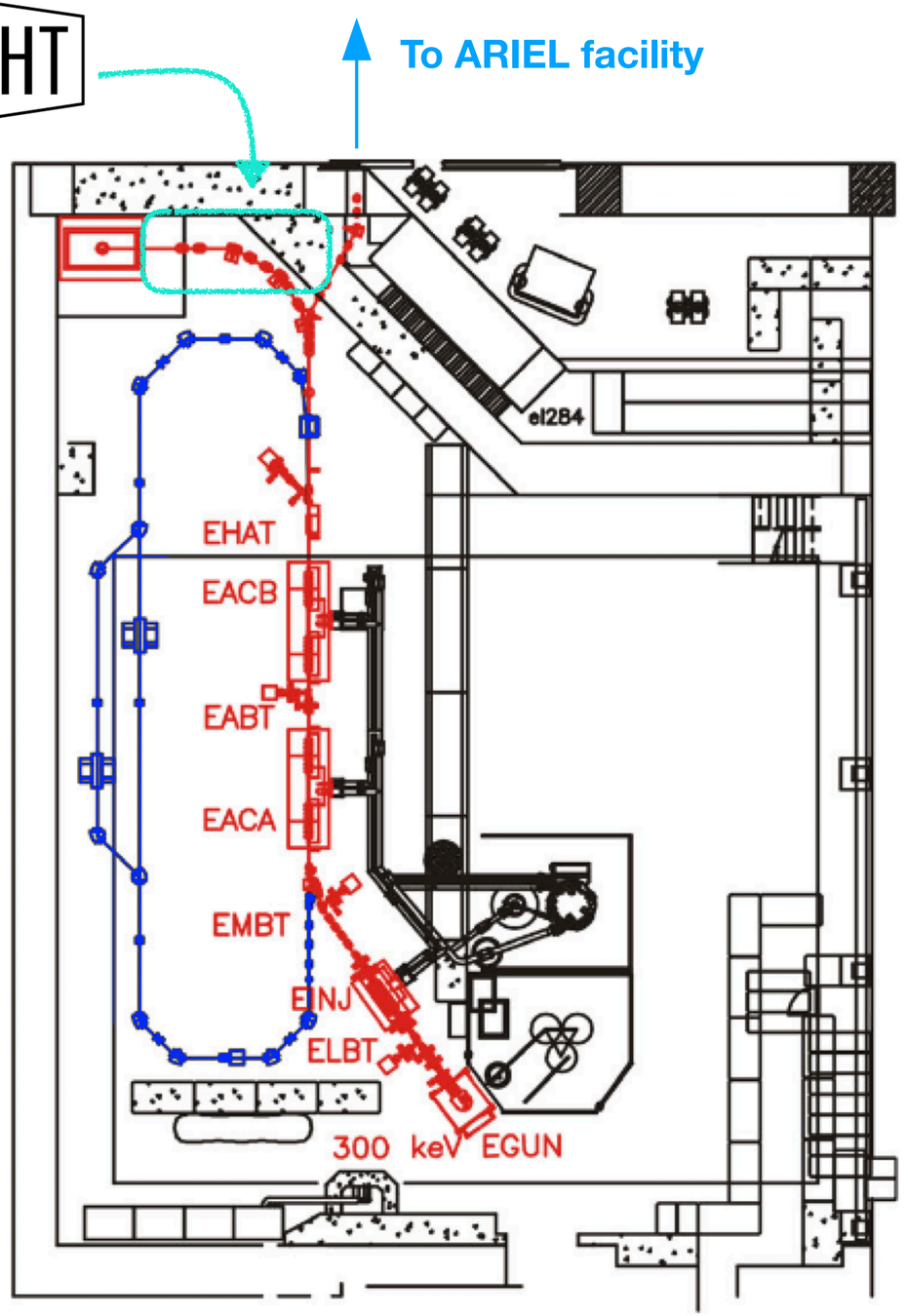
- 30 MeV electron beam setup
- Possible to add a recirculating ring to increase energy to 50 MeV



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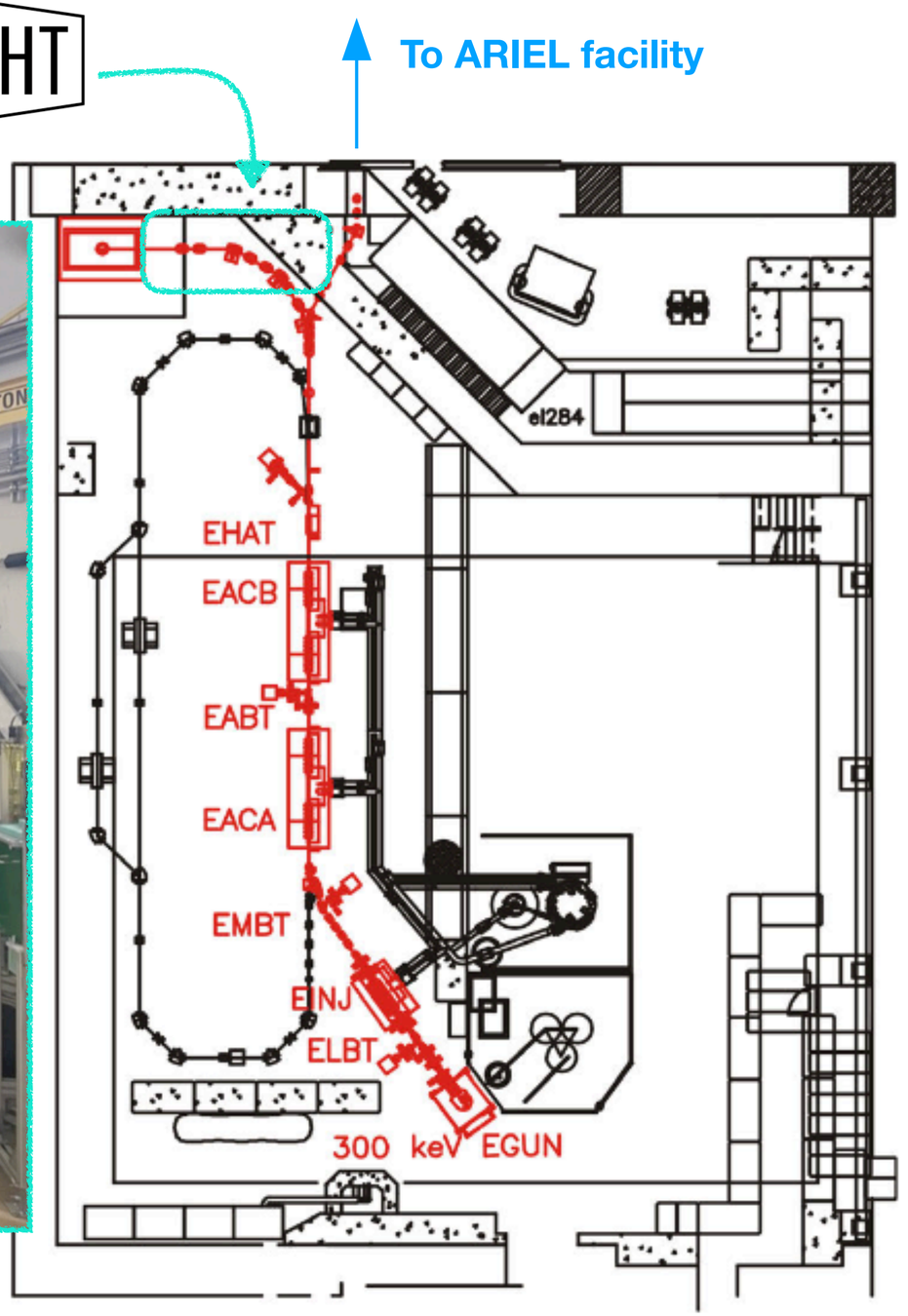

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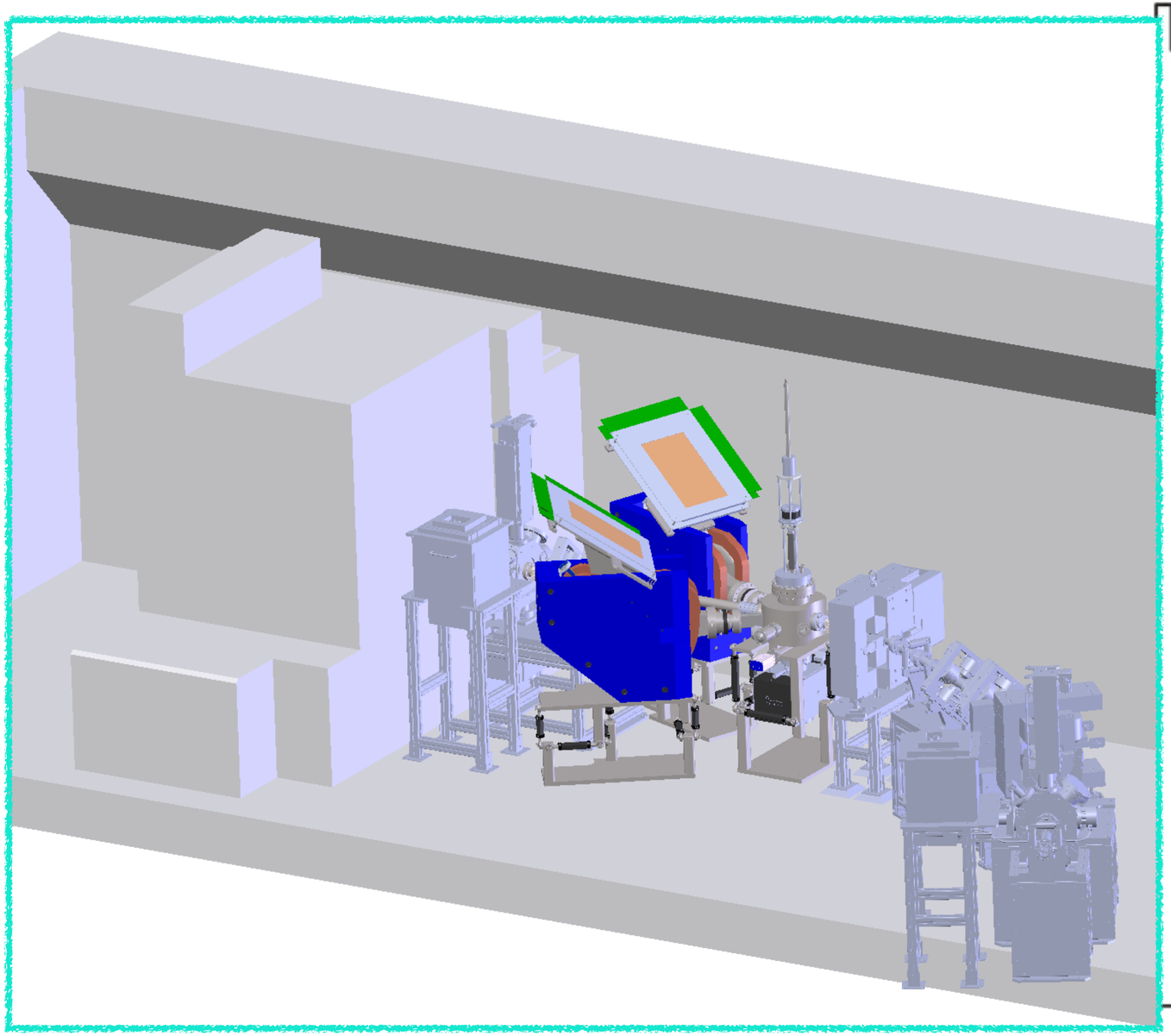
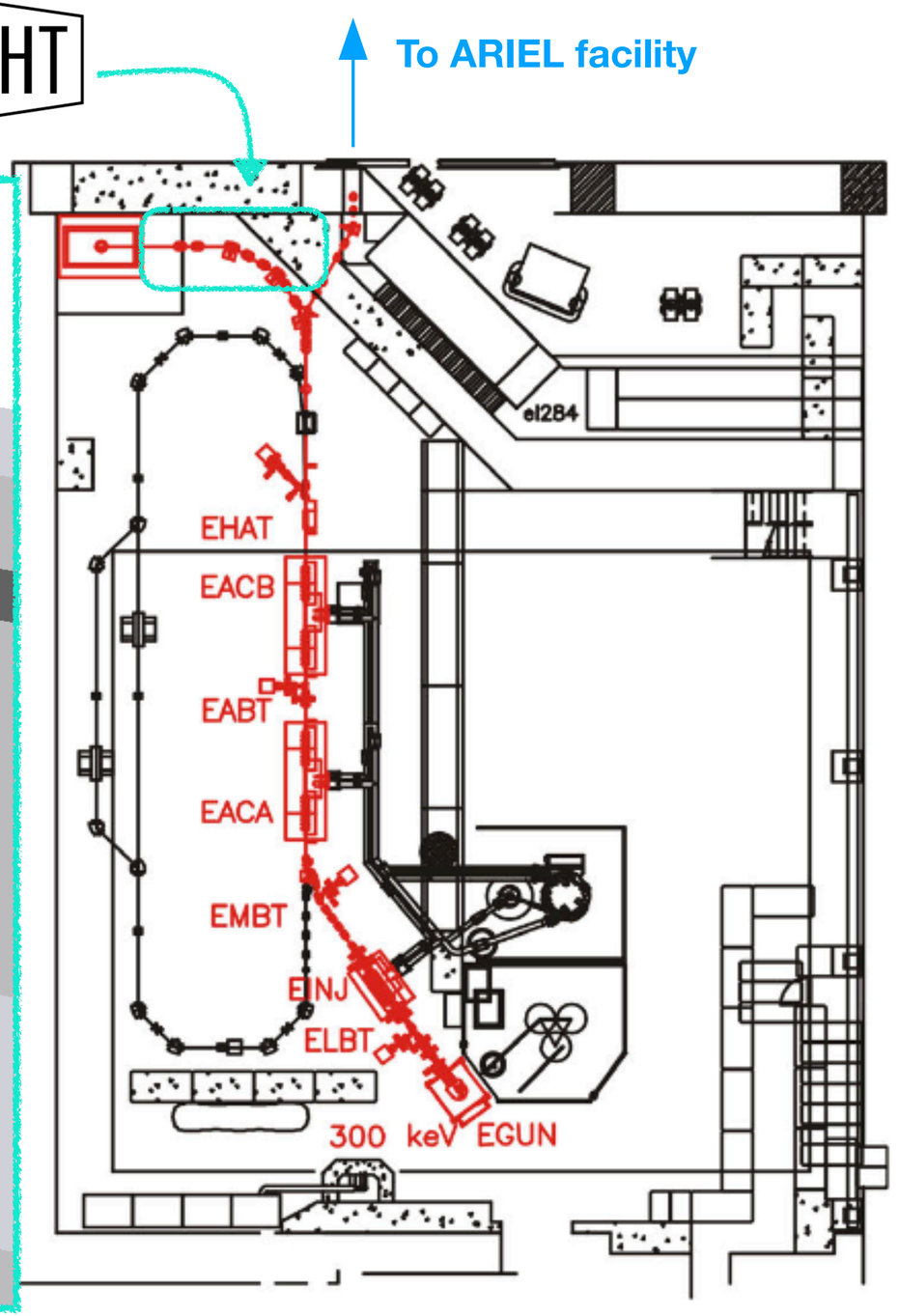
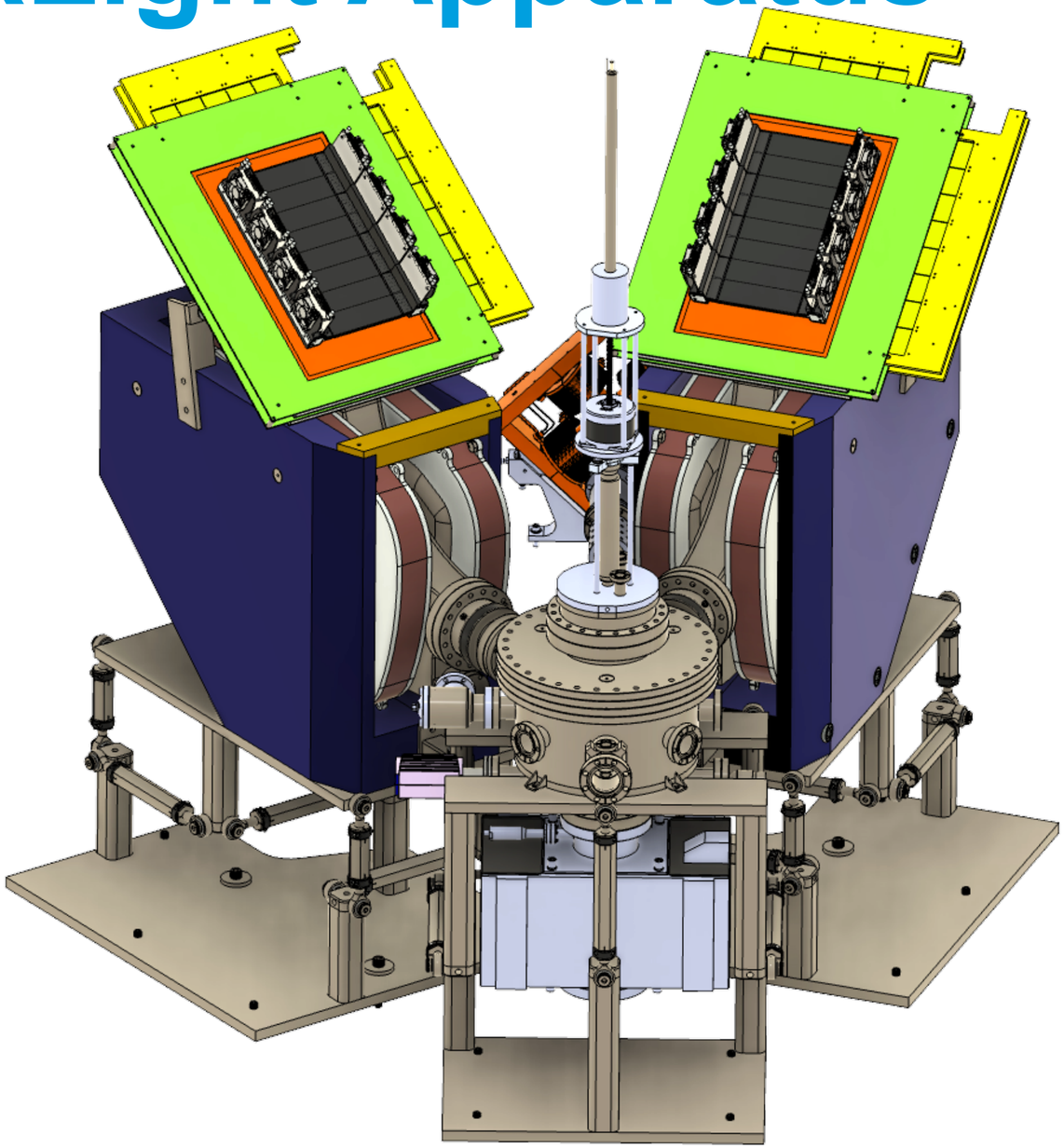
DARKLIGHT





The DarkLight Apparatus



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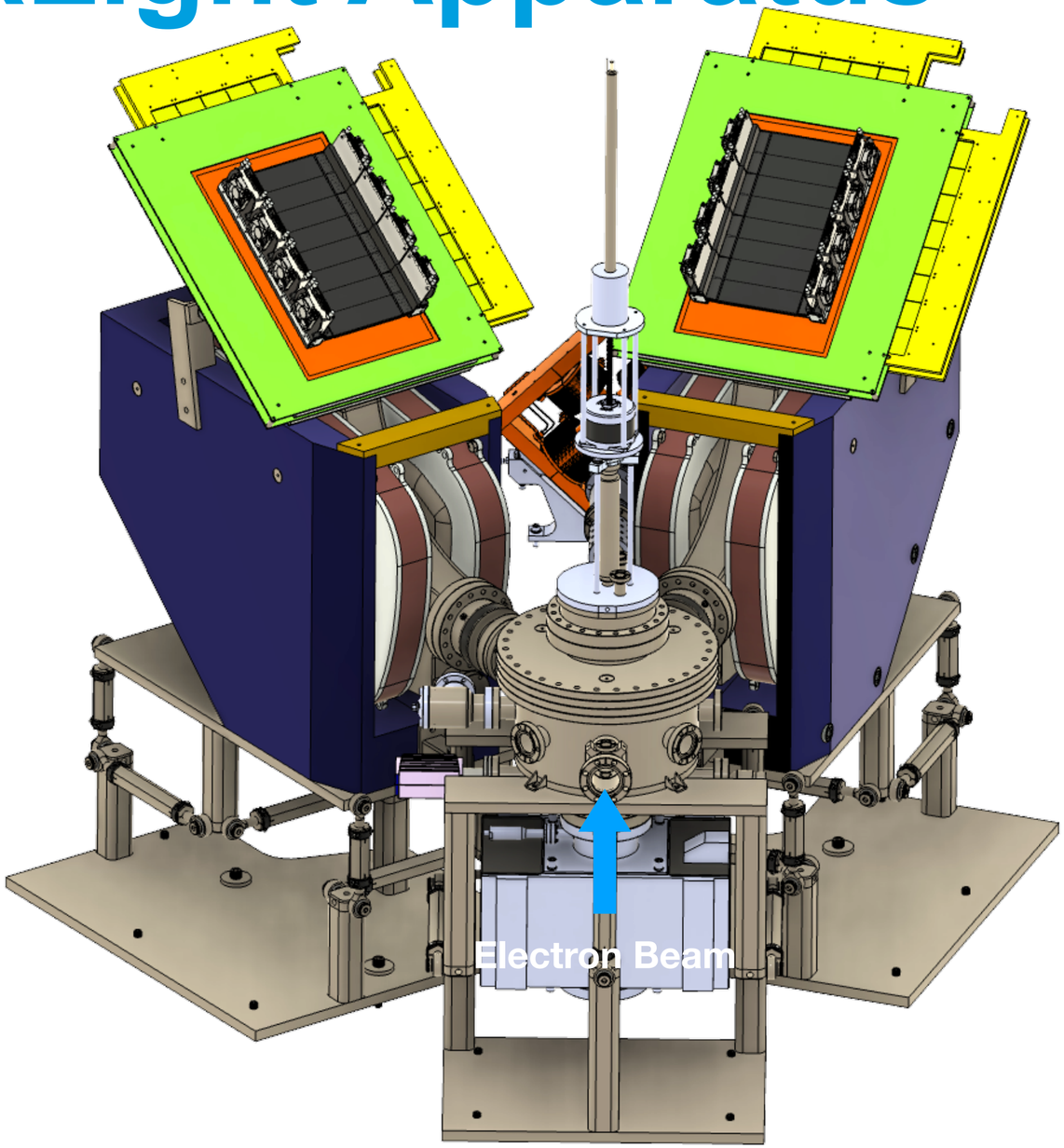
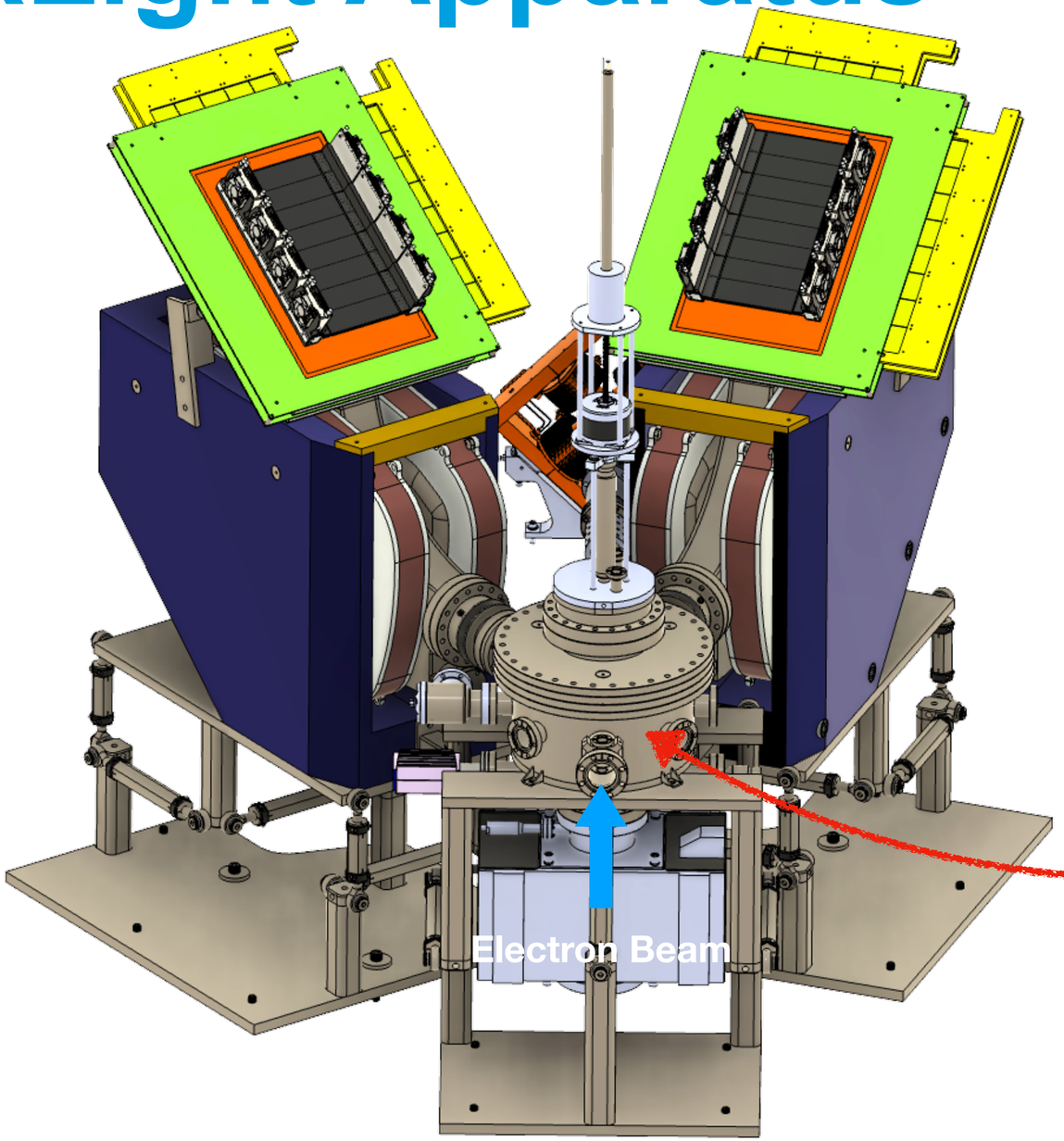
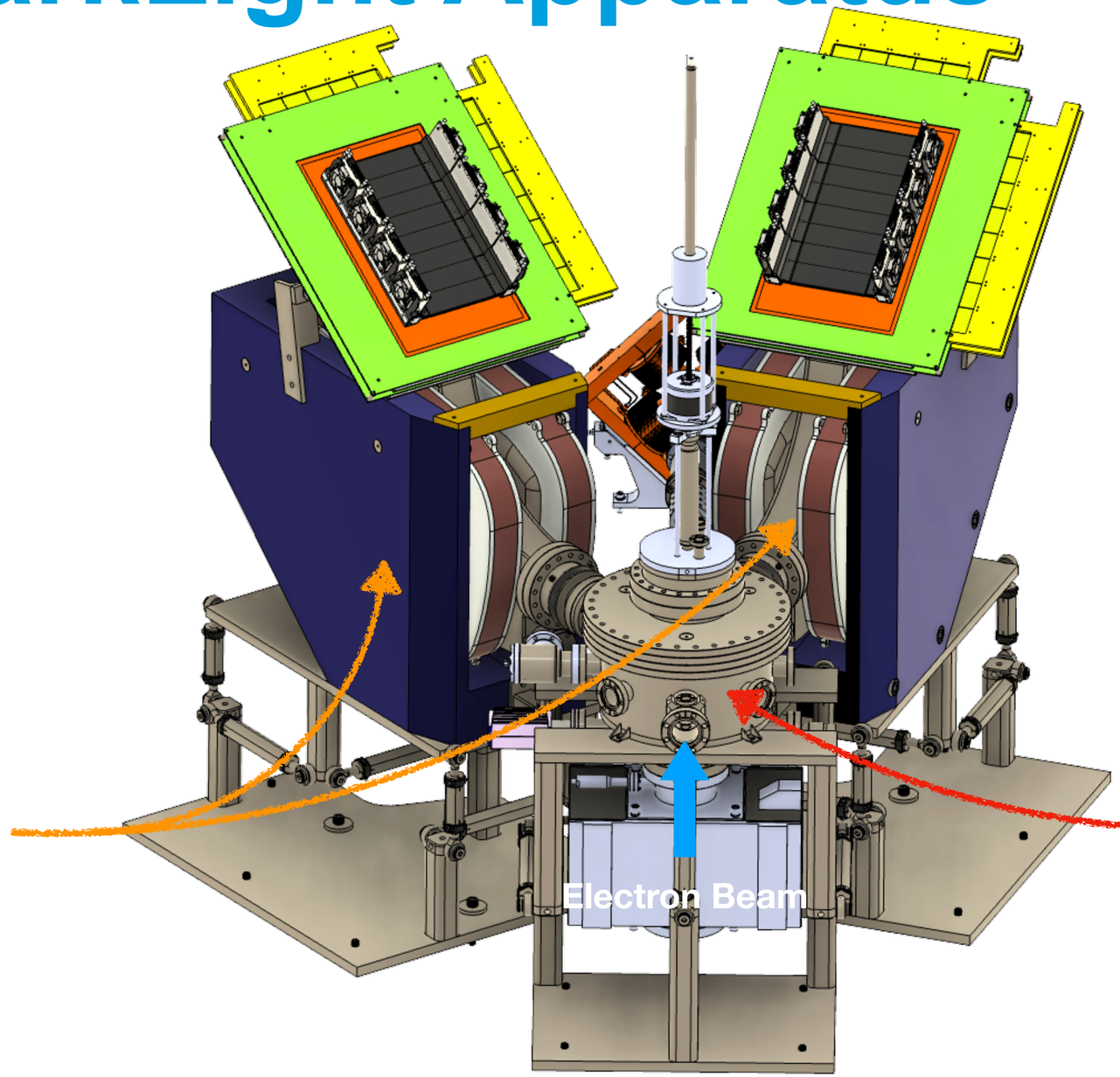


The DarkLight Apparatus



Target chamber with
1 μm Tantalum target

The DarkLight Apparatus



Spectrometers

Left: electrons
Right: positrons

Target chamber with
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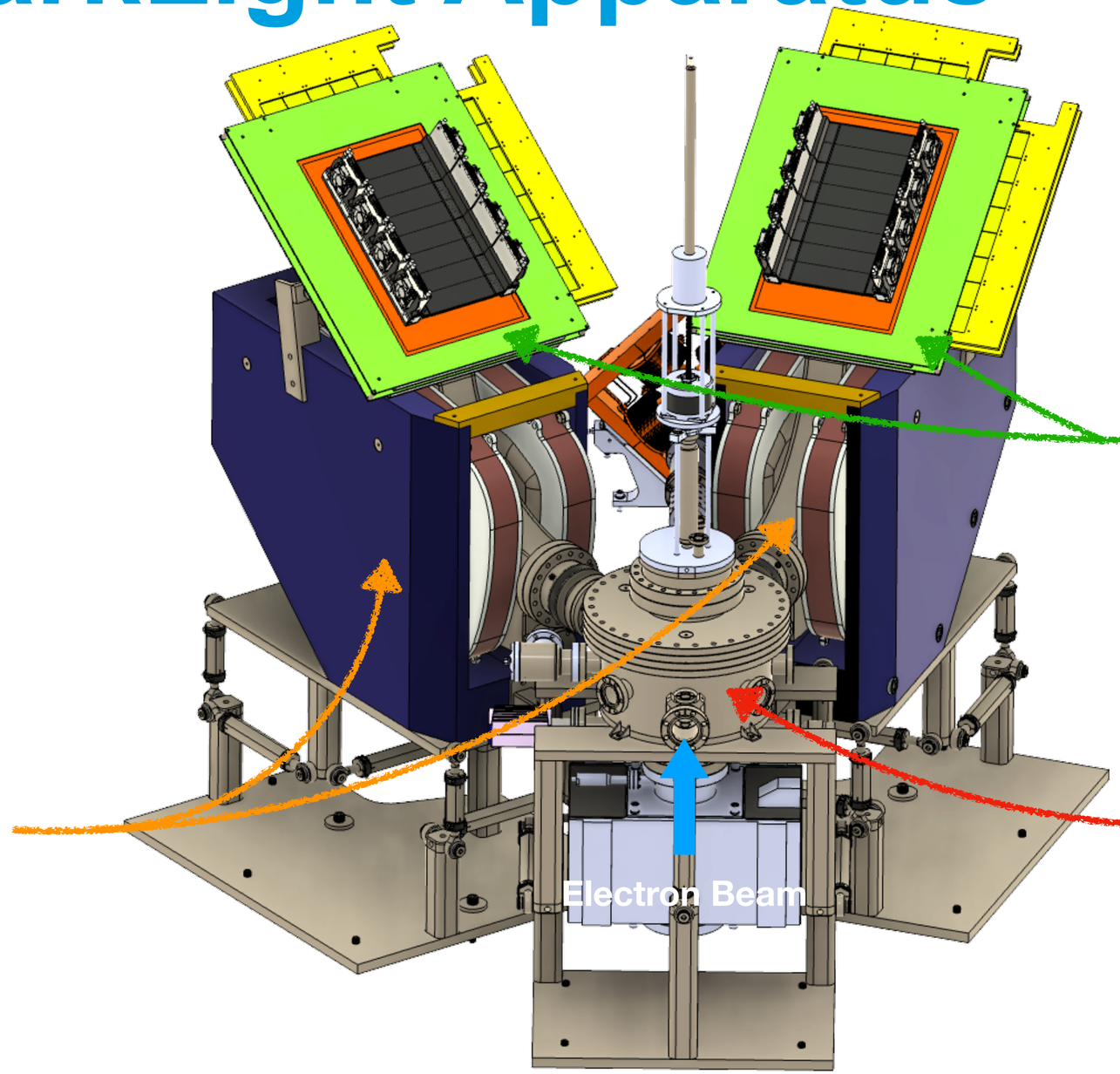
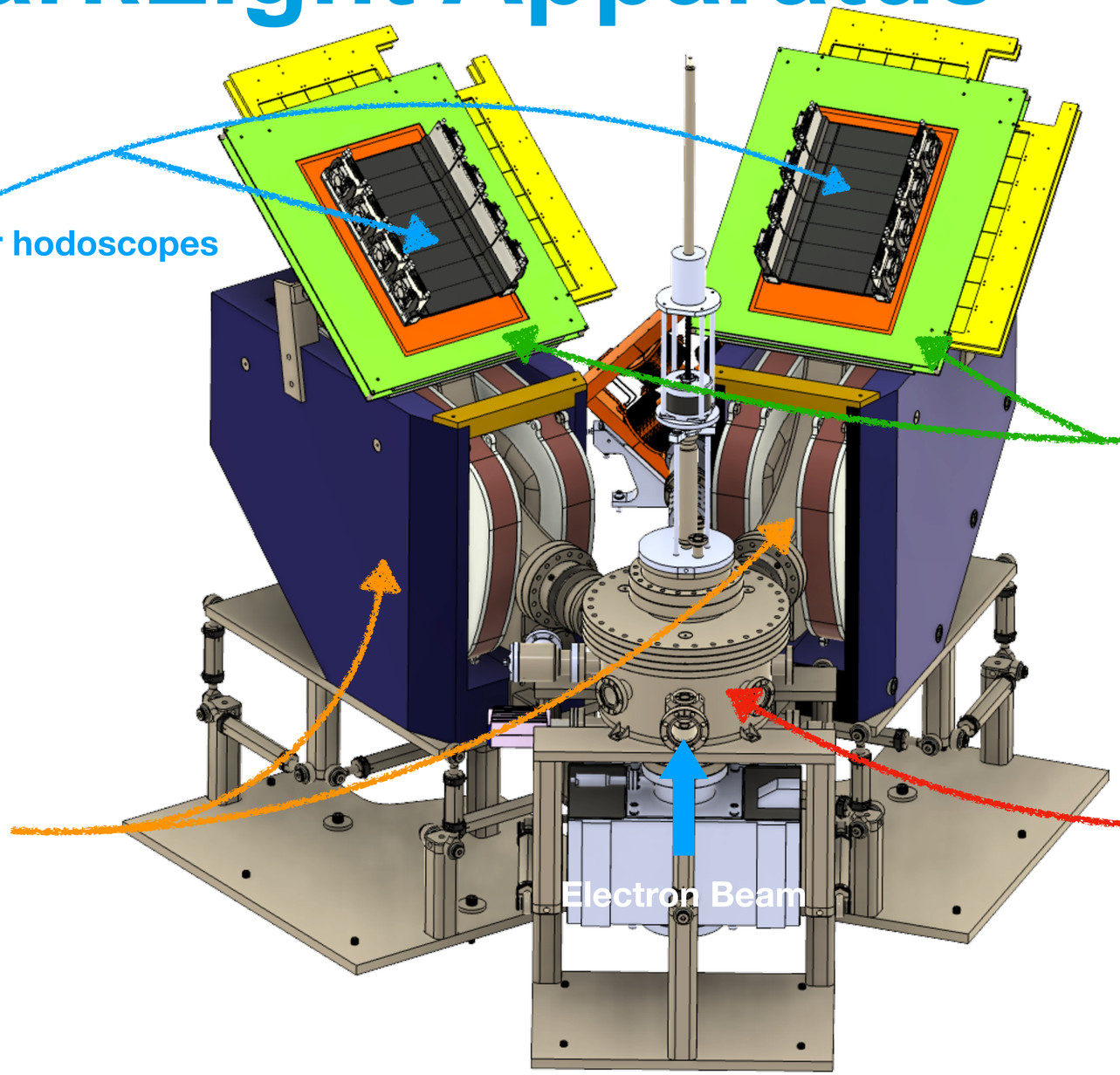
The DarkLight Apparatus



The DarkLight Apparatus



Plastic scintillator trigger hodoscopes

2x GEM tracking detectors

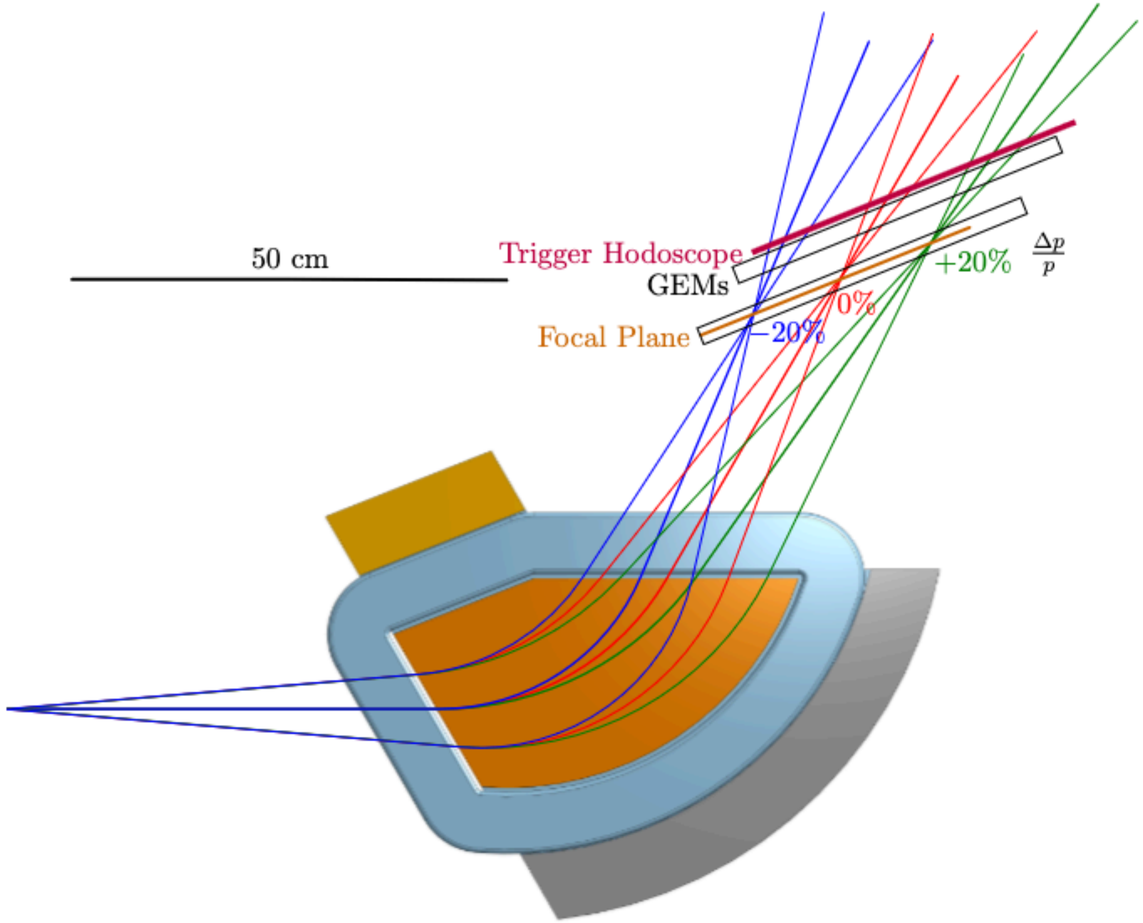
Spectrometers

Left: electrons
Right: positrons

Target chamber with
1 μm Tantalum target

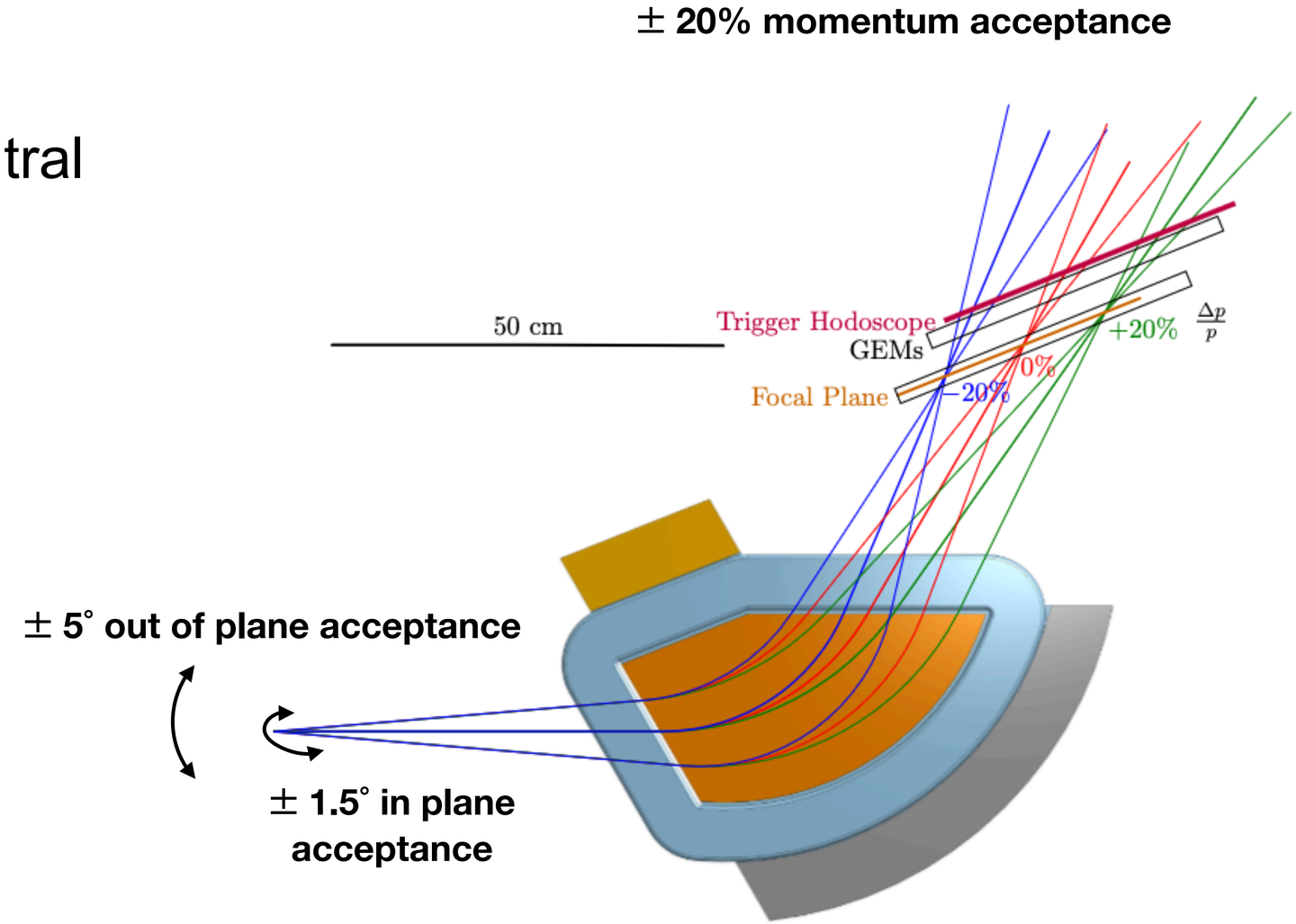
Spectrometers

- Two dipole spectrometers (0.32 T, maximum 28 MeV central momentum)



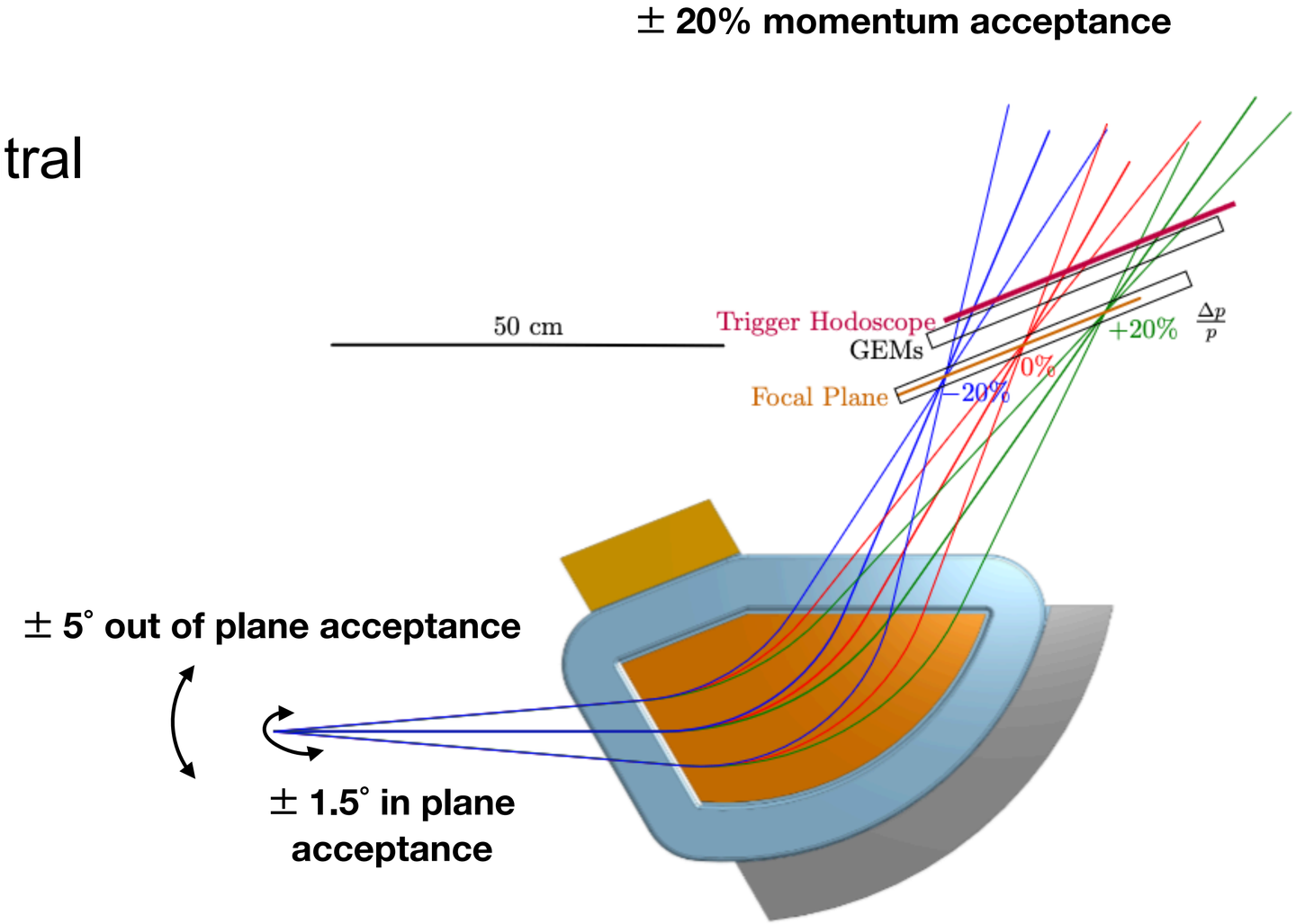
Spectrometers

- Two dipole spectrometers (0.32 T, maximum 28 MeV central momentum)
- Mass resolution ≈ 120 keV



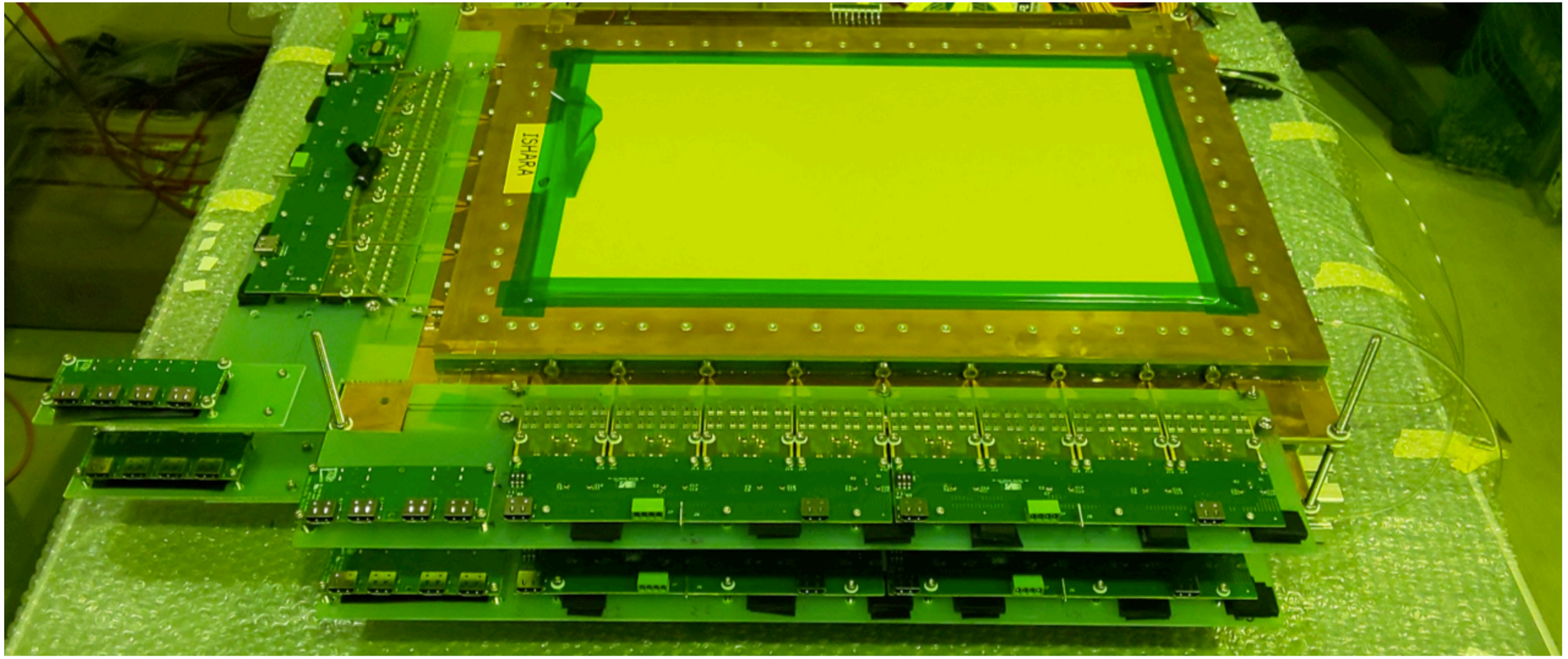
Spectrometers

- Two dipole spectrometers (0.32 T, maximum 28 MeV central momentum)
- Mass resolution ≈ 120 keV
- For 30 MeV e^- beam: e^- spectrometer arm at angle of 20˚, e^+ arm at 36˚
- On order, should arrive later this year



GEMs

- Preexisting 25 cm × 40 cm triple-GEMs built by Hampton University
- Testing underway in parallel at Hampton and TRIUMF



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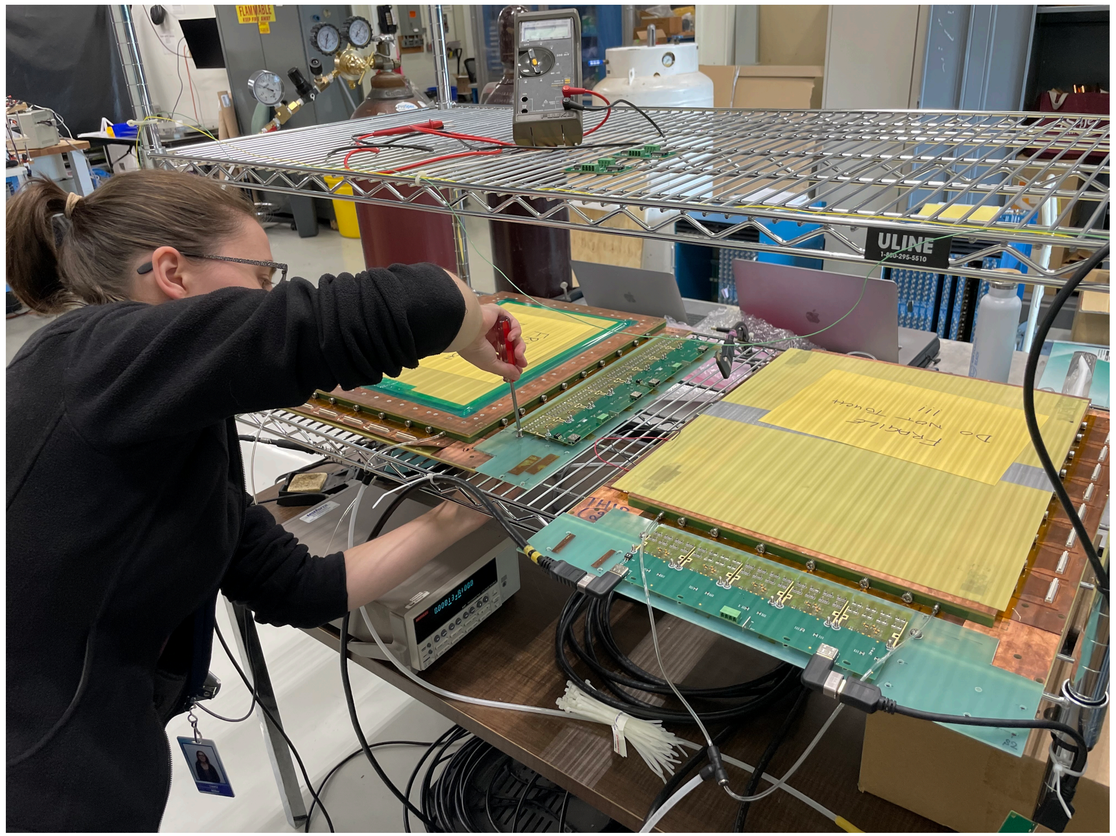
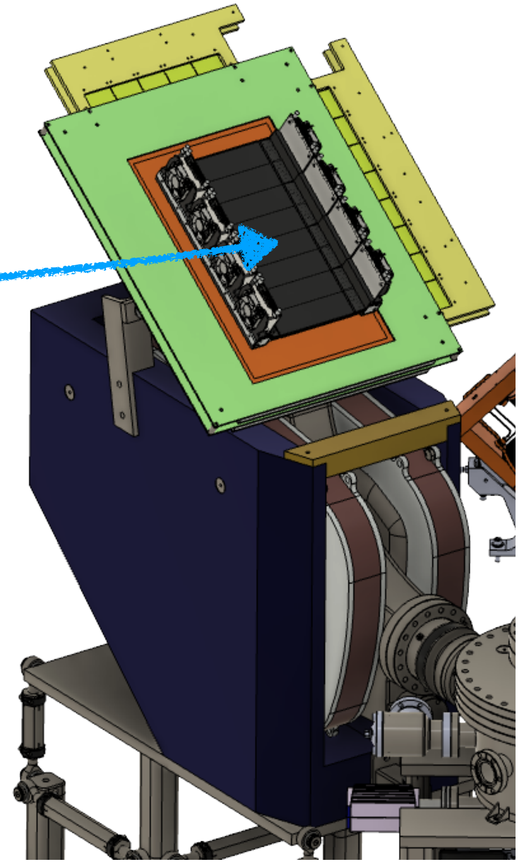


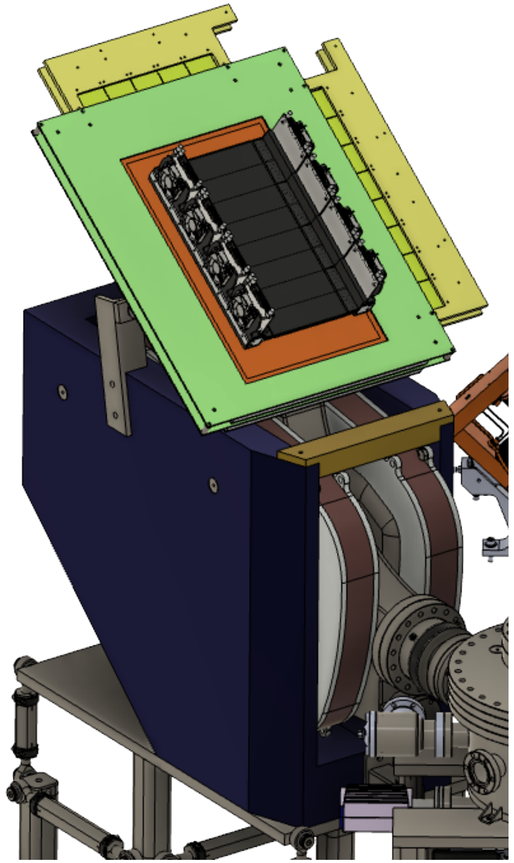
Triggers

- Eight fast plastic scintillator strips on each spectrometer arm



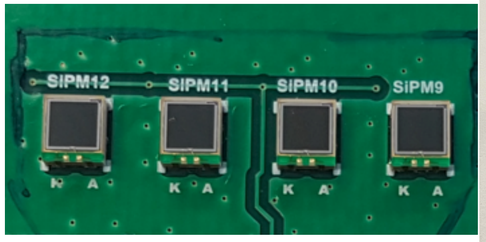
Triggers

- Eight fast plastic scintillator strips on each spectrometer arm
- Designed for timing resolution of around 200 ps
  (< 500 ps required to resolve bunches)



Triggers

- Eight fast plastic scintillator strips on each spectrometer arm
- Designed for timing resolution of around 200 ps (< 500 ps required to resolve bunches)
- Double ended SiPM readout
  - 6 SiPMs per strip per end
  - One card holds 12 SiPMs



Slightly older prototype
to show light guides

Triggers

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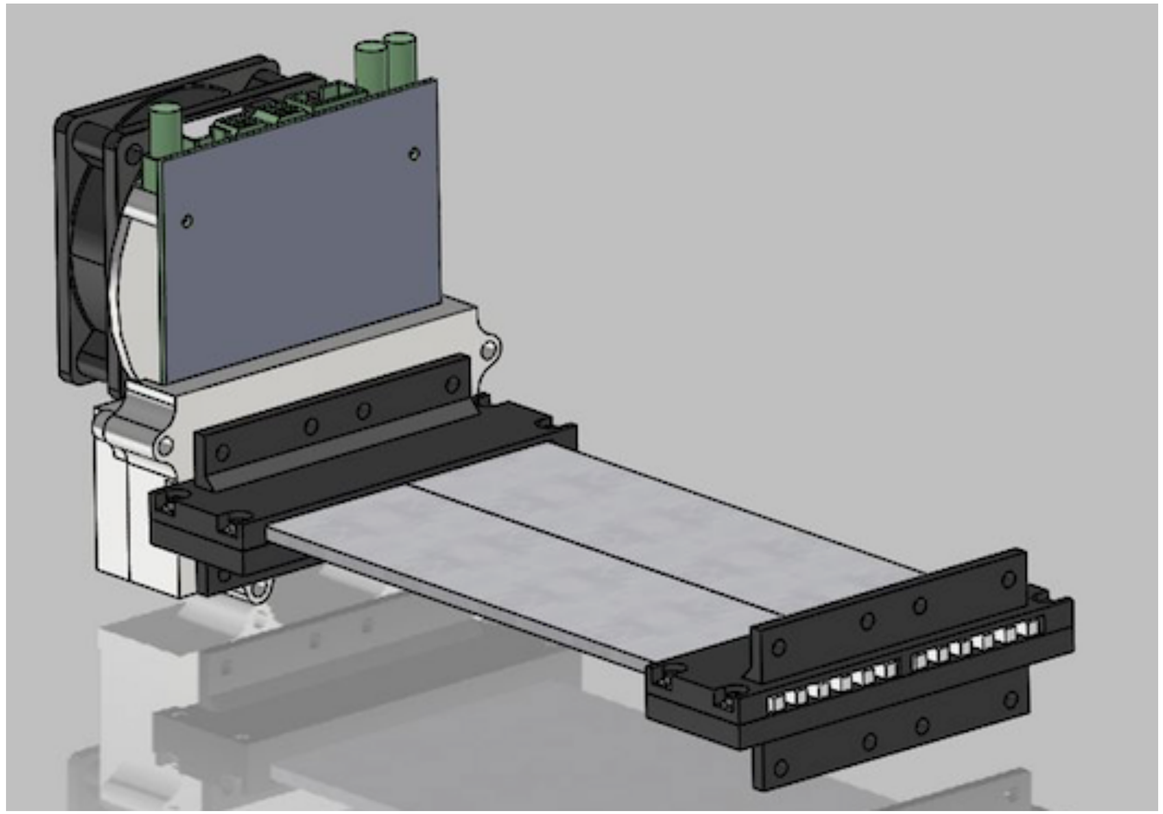

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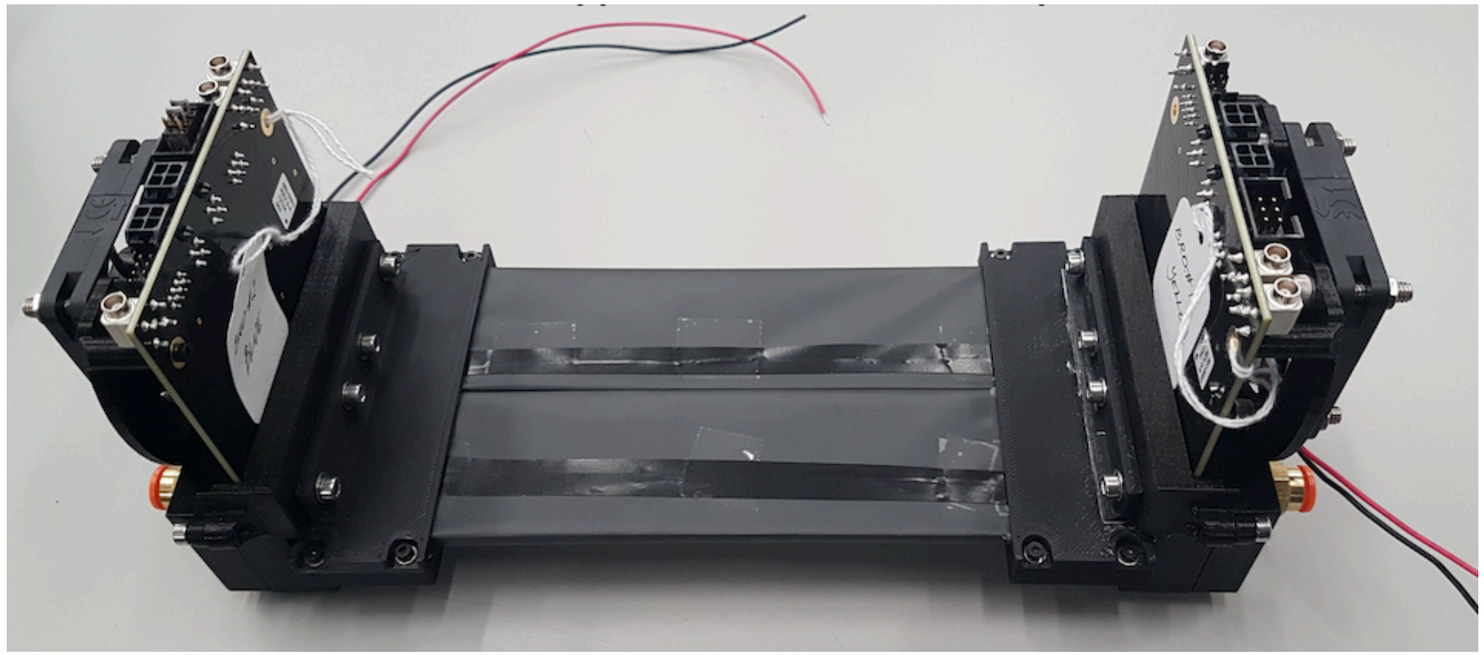
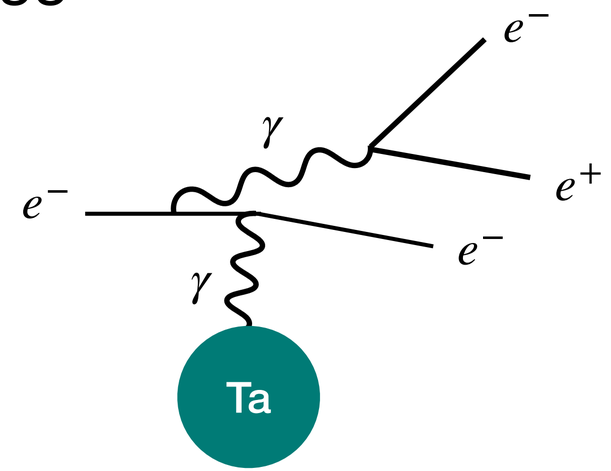


Triggers

- Eight fast plastic scintillator strips on each spectrometer arm
- Designed for timing resolution of around 200 ps
  (< 500 ps required to resolve bunches)
- Double ended SiPM readout
  - 6 SiPMs per strip per end
  - One card holds 12 SiPMs
- Final stages of prototyping and DAQ testing underway at TRIUMF, preparing to integrate with the GEM DAQ

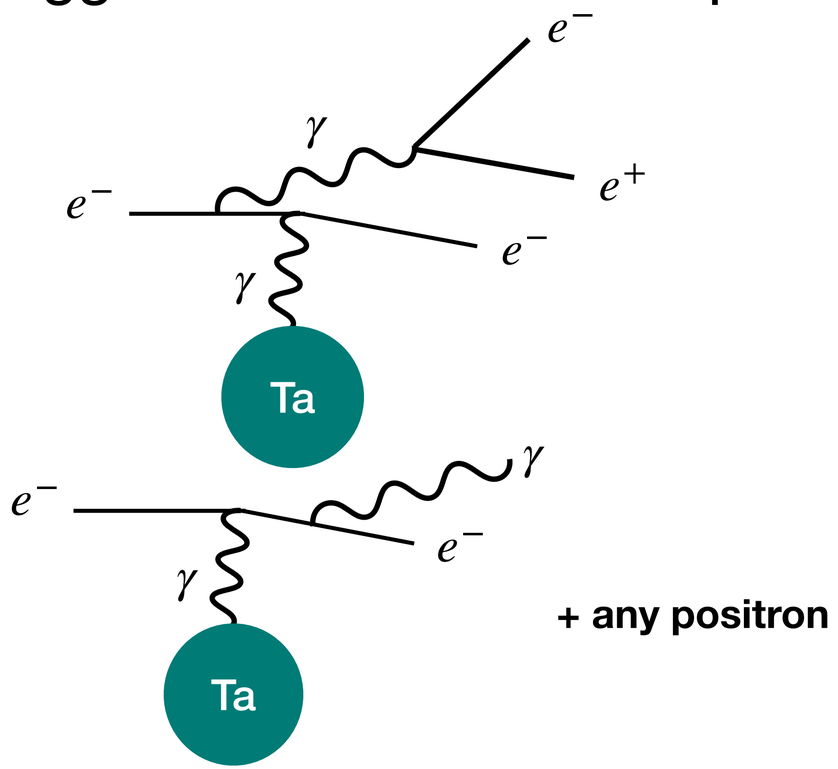
Projected Sensitivities

- Require coincidence in trigger from electron and positron arm to readout GEMs
- Irreducible background:



Projected Sensitivities

- Require coincidence in trigger from electron and positron arm to readout GEMs
- Irreducible background:
- Reducible background:



+ any positron

Projected Sensitivities

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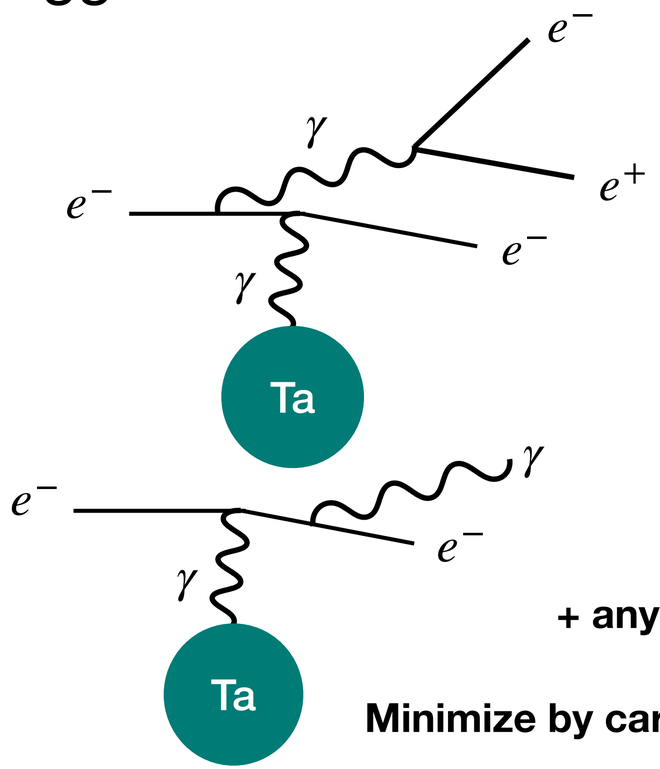
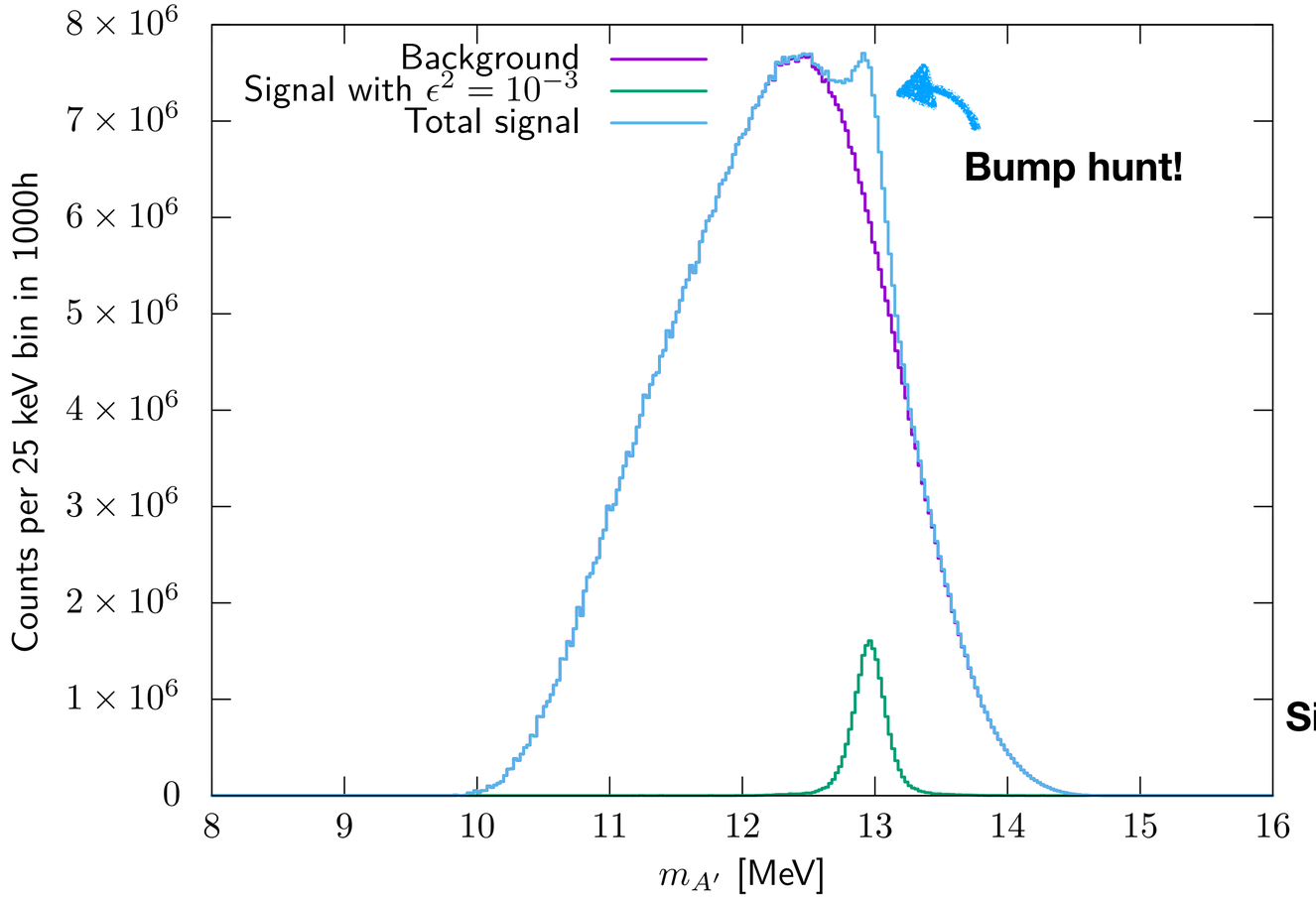


+ any positron

Minimize by carefully selecting spectrometer arm angles
Can be well-modelled

Projected Sensitivities

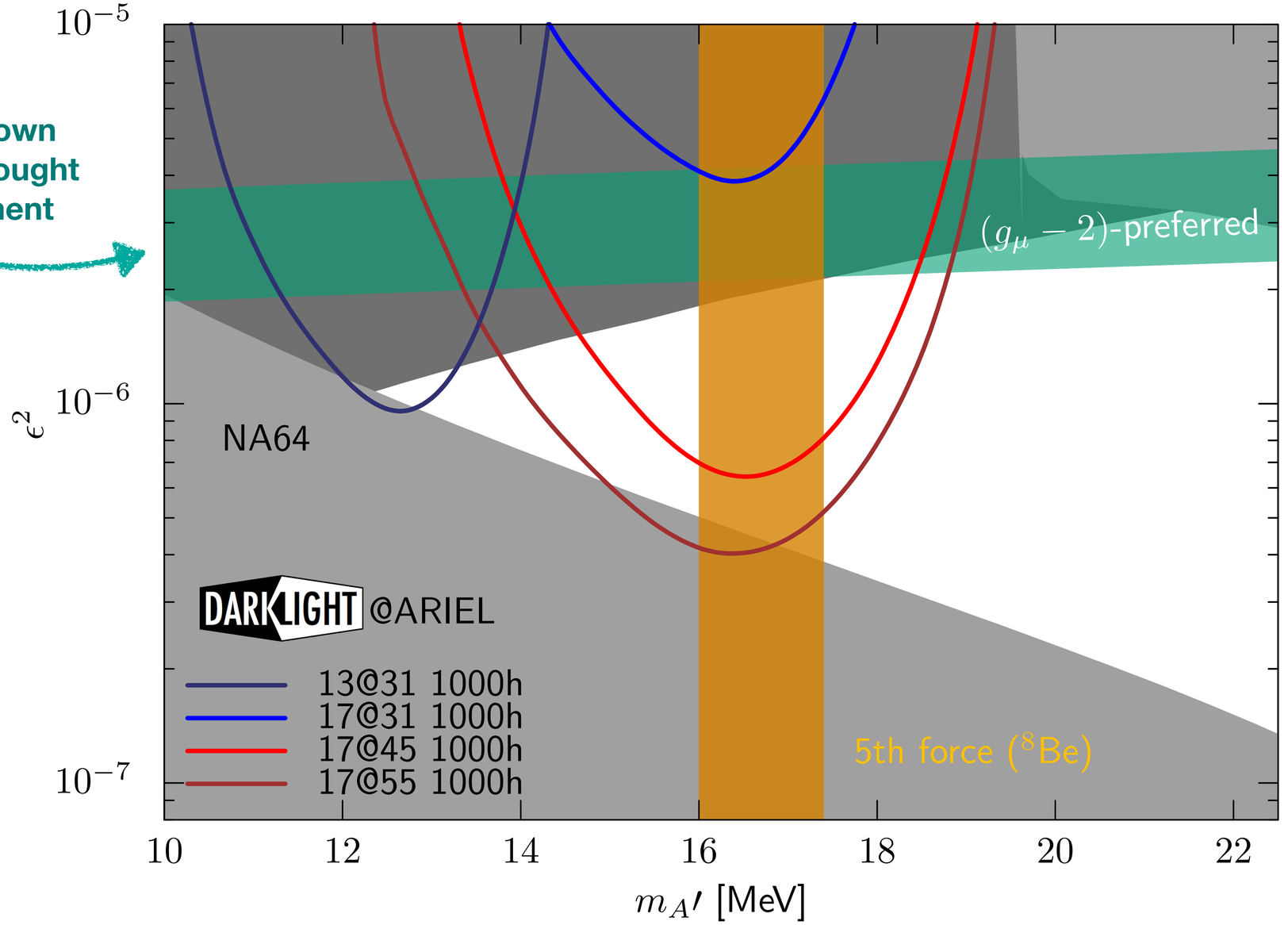
- Require coincidence in trigger from electron and positron arm to readout GEMs



Signal exaggerated for illustration

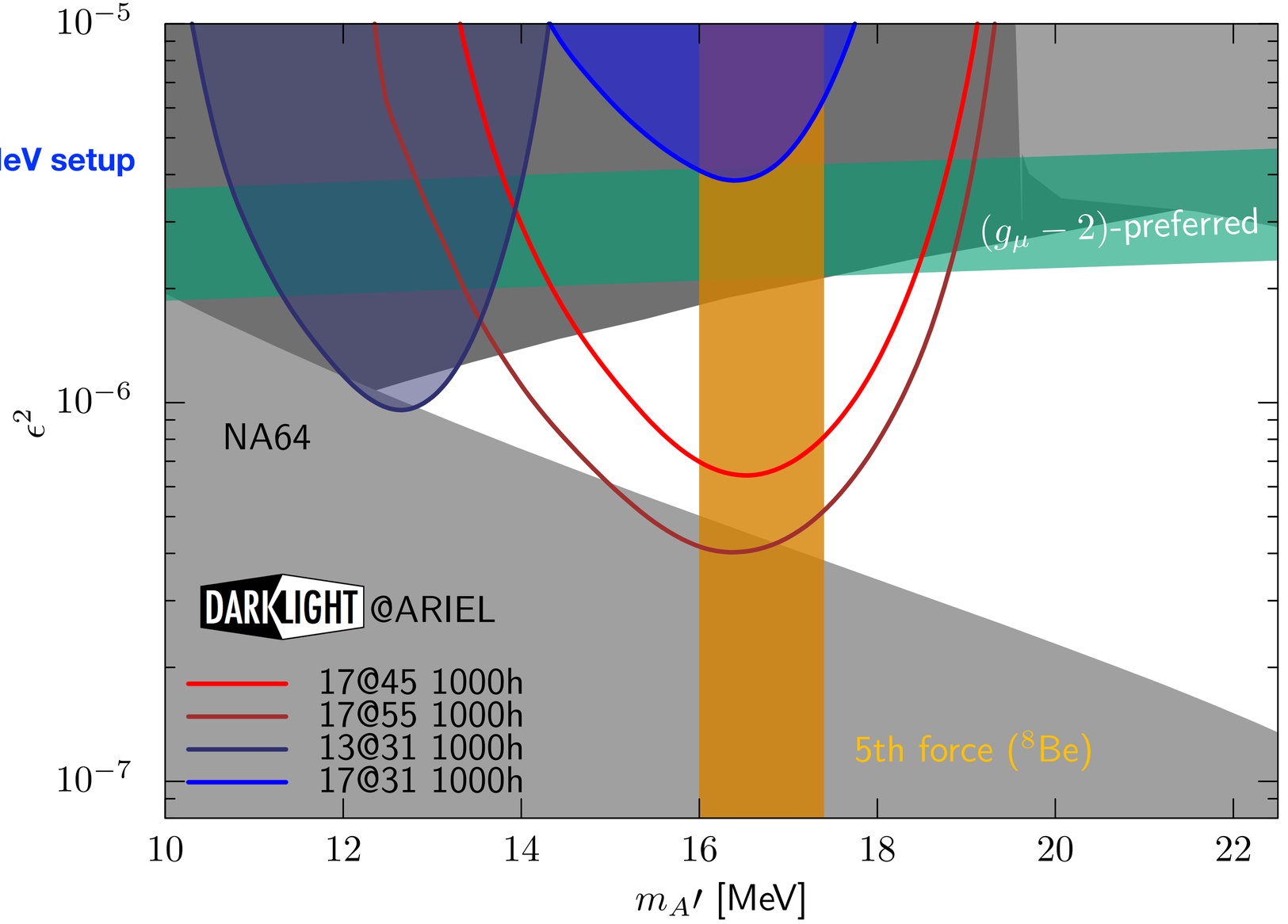
Projected Sensitivities

Will move slightly down if SM prediction is brought closer to measurement

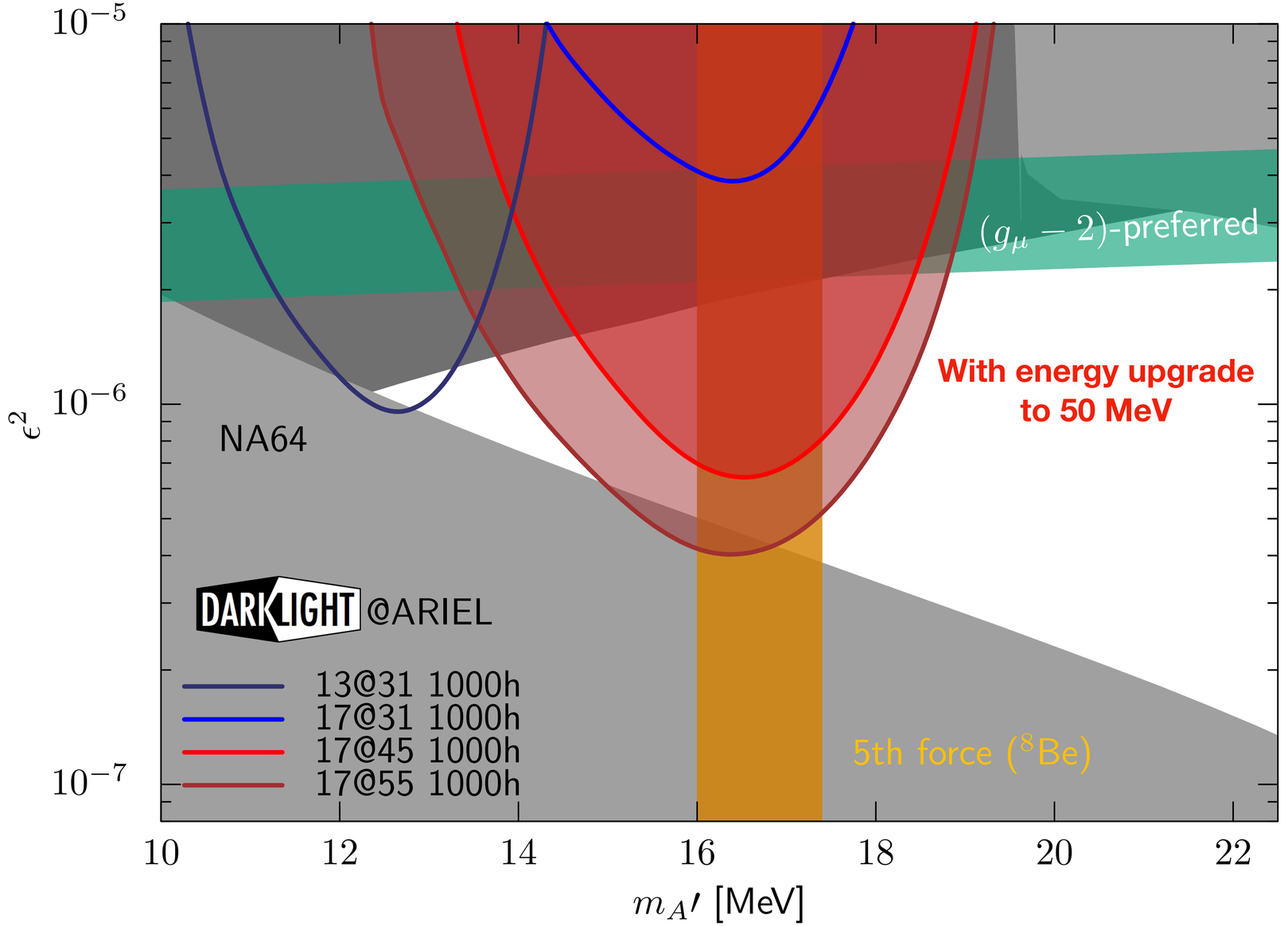


Projected Sensitivities

With current 30 MeV setup



Projected Sensitivities



Conclusion

- Collaboration is hard at work with commissioning
- With current 30 MeV setup:
  - Full installation by the end of this year
  - 1000 hours of beam time
  - Cannot probe the X17 region, but gives us an opportunity to fine tune the detector, get thorough understanding of the backgrounds etc.
- With future 50 MeV setup (seeking funding): can probe majority of the uncovered X17 favoured region

Thanks for listening! Questions?