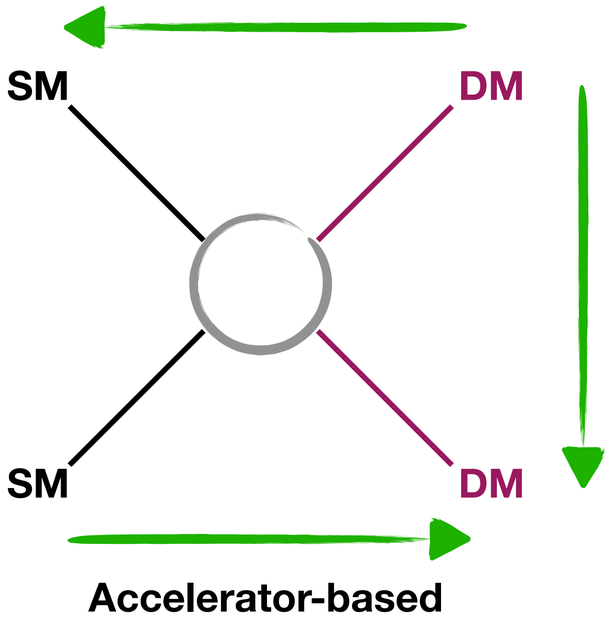
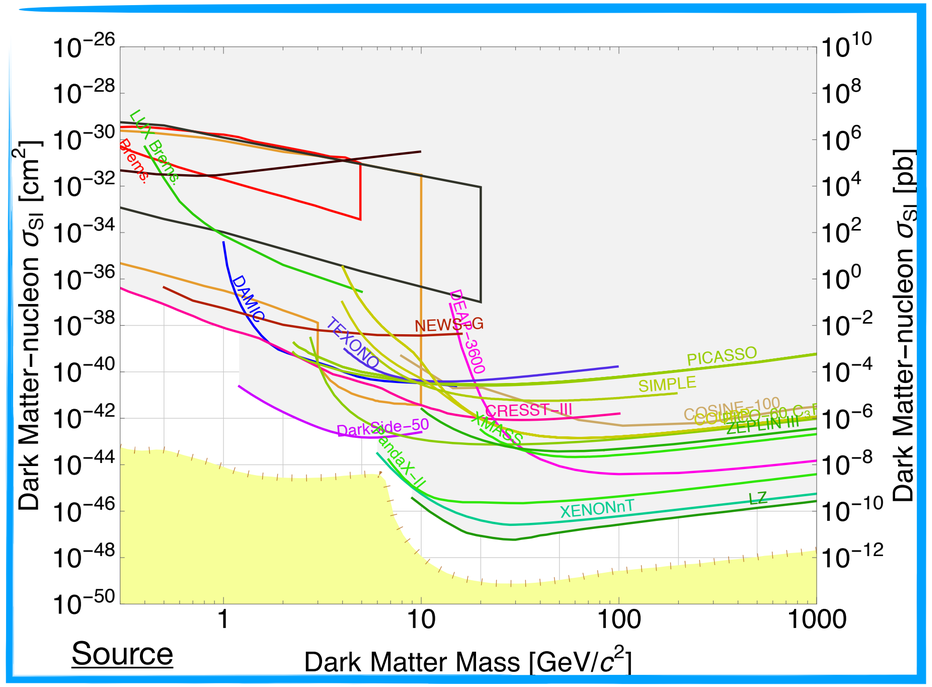
Exploring Hidden Sectors at the DarkLight Experiment

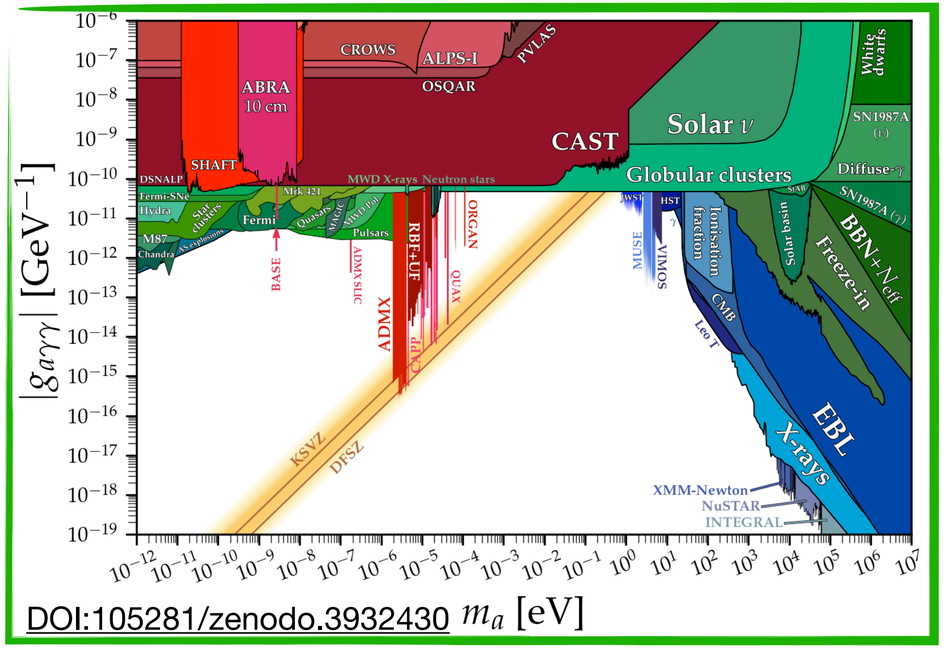
Laura Miller
Light Dark World, Carleton University, Ottawa
2026-07-30

Dark Matter Searches



- One of the largest open questions in particle physics
- Large historical focus on weakly interacting massive particles (WIMPs) and axions
- No evidence found so far

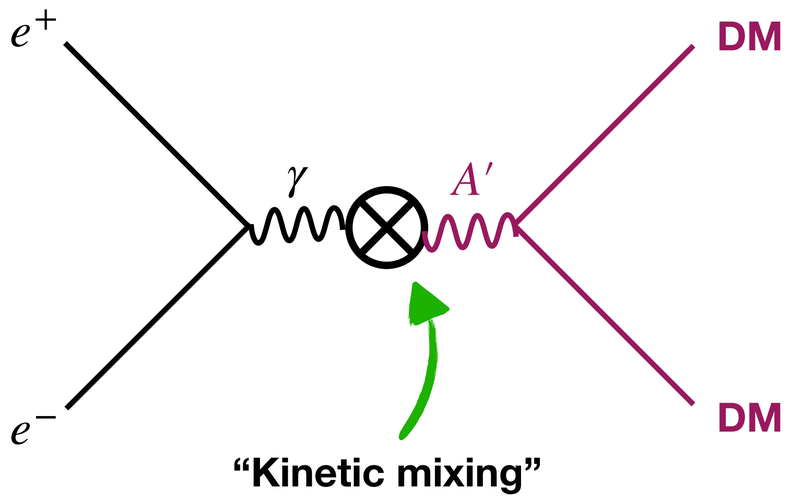




Dark Photon Model

- Dark photon implies an additional U(1) gauge group in the Standard Model
- Results in an additional interaction term of the form

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



Dark Photon Model

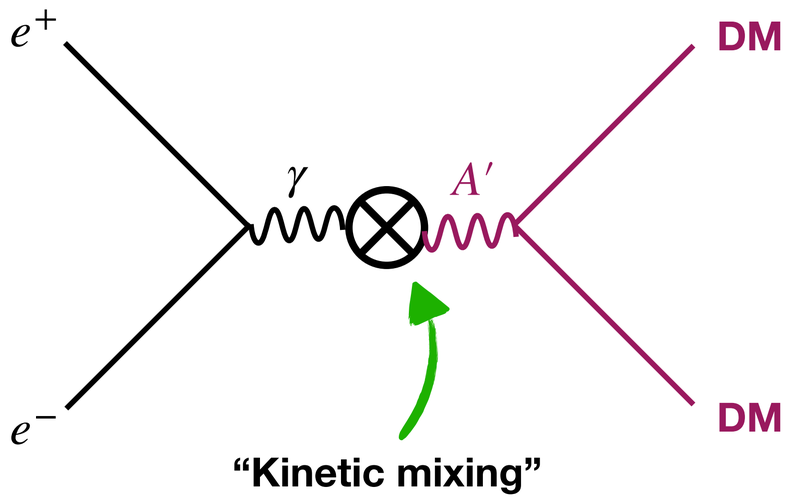
- Dark photon implies an additional U(1) gauge group in the Standard Model
- Results in an additional interaction term of the form

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

Kinetic mixing strength

Dark photon

SM QED current



Dark Photon Model

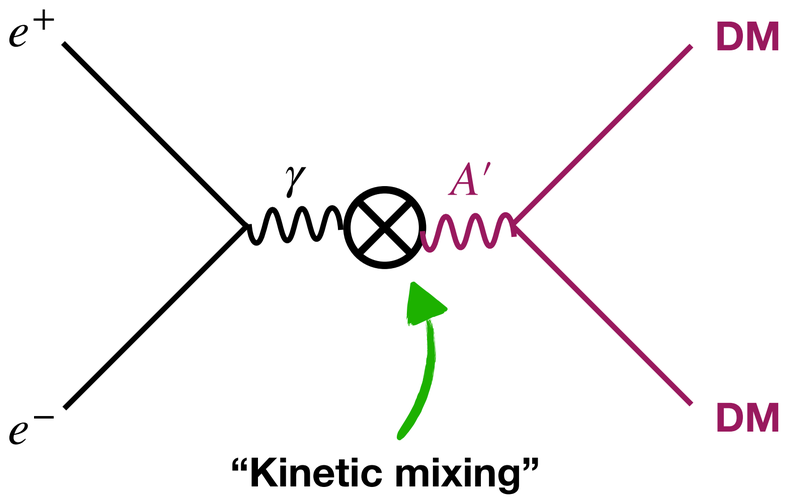
- Dark photon implies an additional U(1) gauge group in the Standard Model
- Results in an additional interaction term of the form

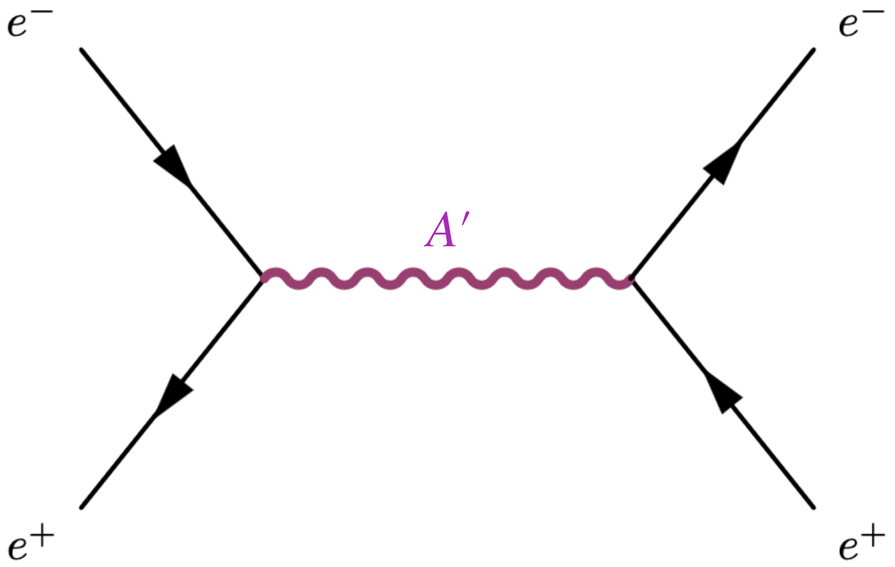
$$\mathscr{L}_{\text{int}} = e\varepsilon J_\mu A'^\mu$$

Kinetic mixing strength

Dark photon

SM QED current





Dark Photon Model

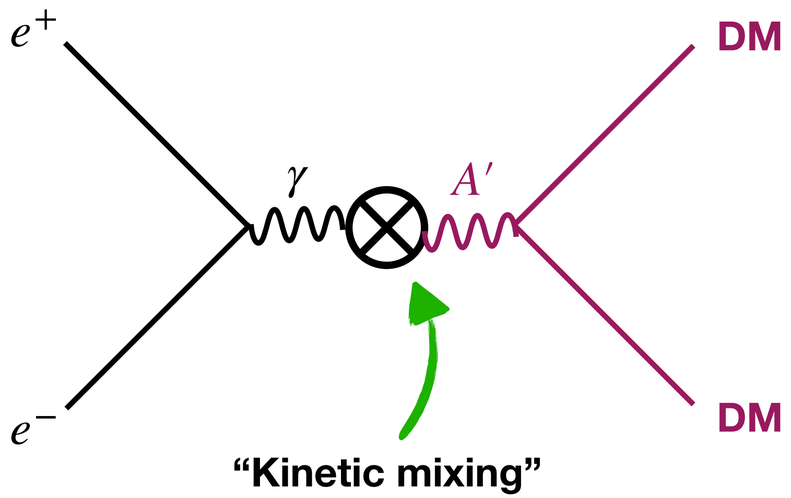
- Dark photon implies an additional U(1) gauge group in the Standard Model
- Results in an additional interaction term of the form

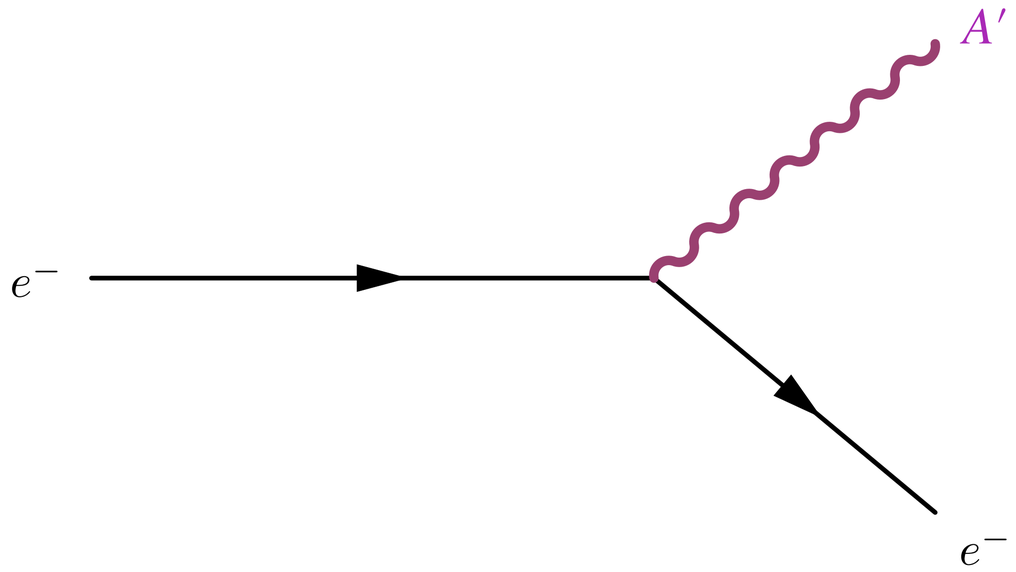
$$\mathscr{L}_{\text{int}} = e\varepsilon J_\mu A'^\mu$$

Kinetic mixing strength

Dark photon

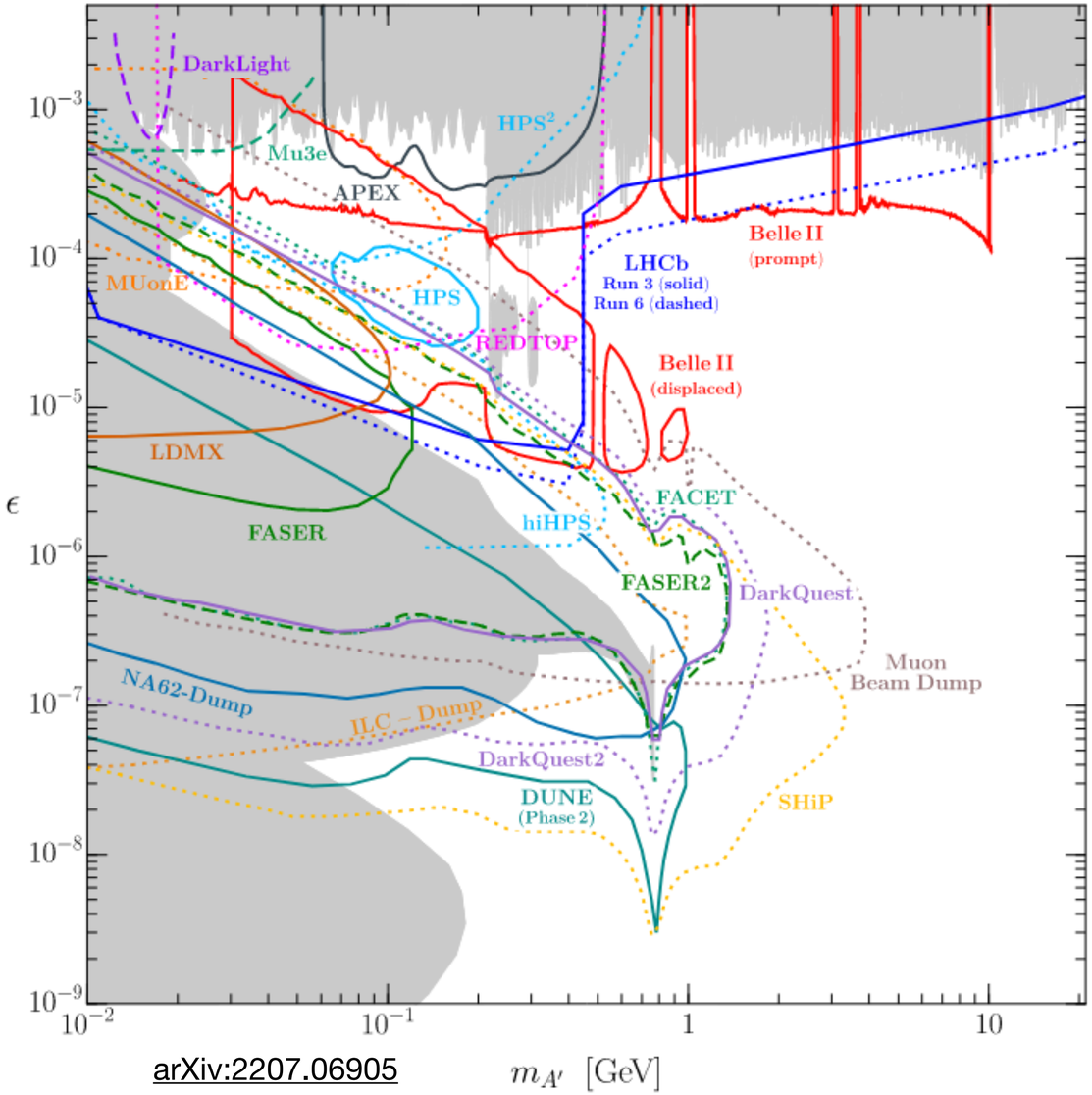
SM QED current





Dark Photons: Current Limits

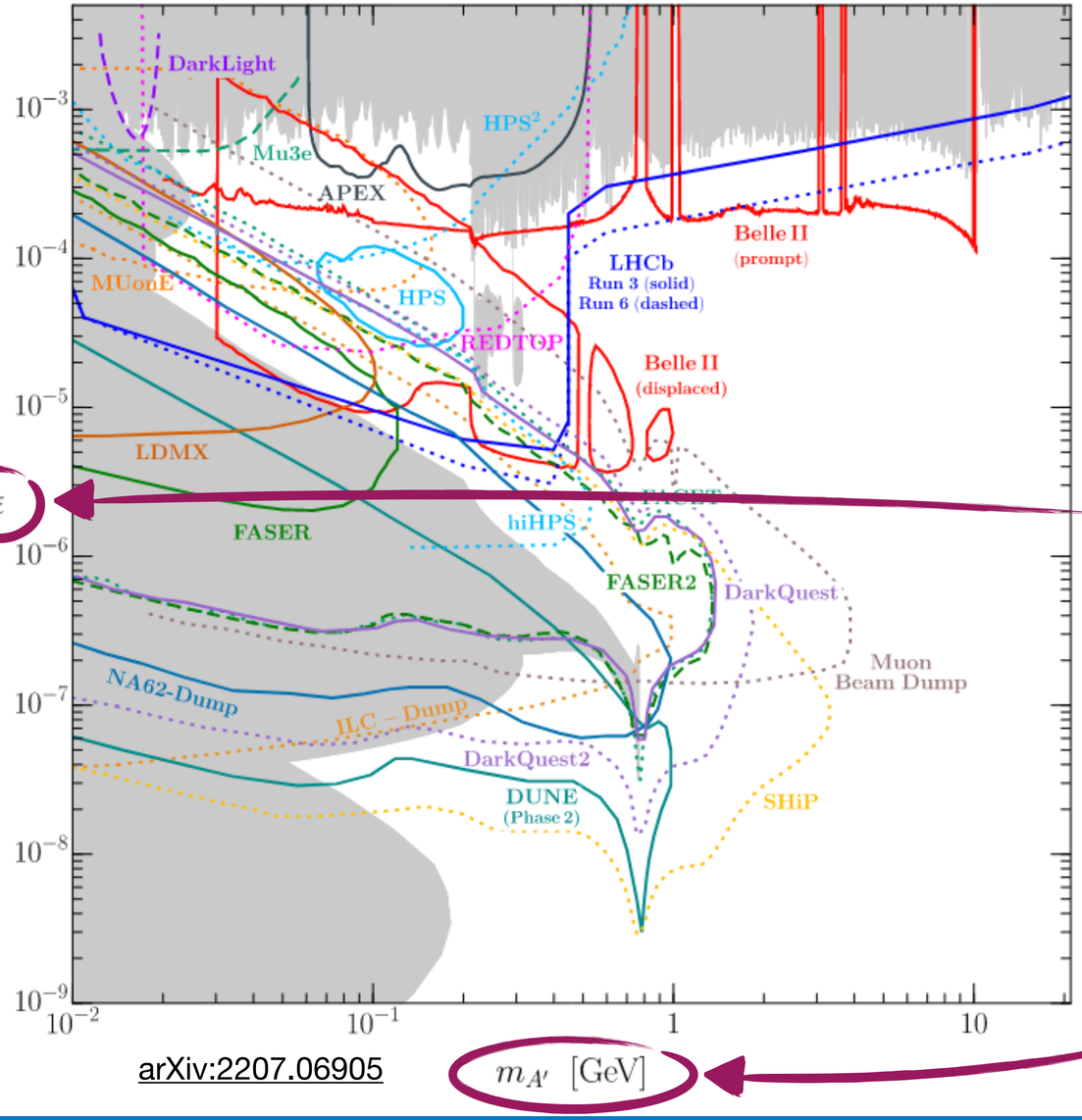
Limits for past (grey) and future dark photon experiments



arXiv:2207.06905

Dark Photons: Current Limits

Limits for past (grey) and future dark photon experiments

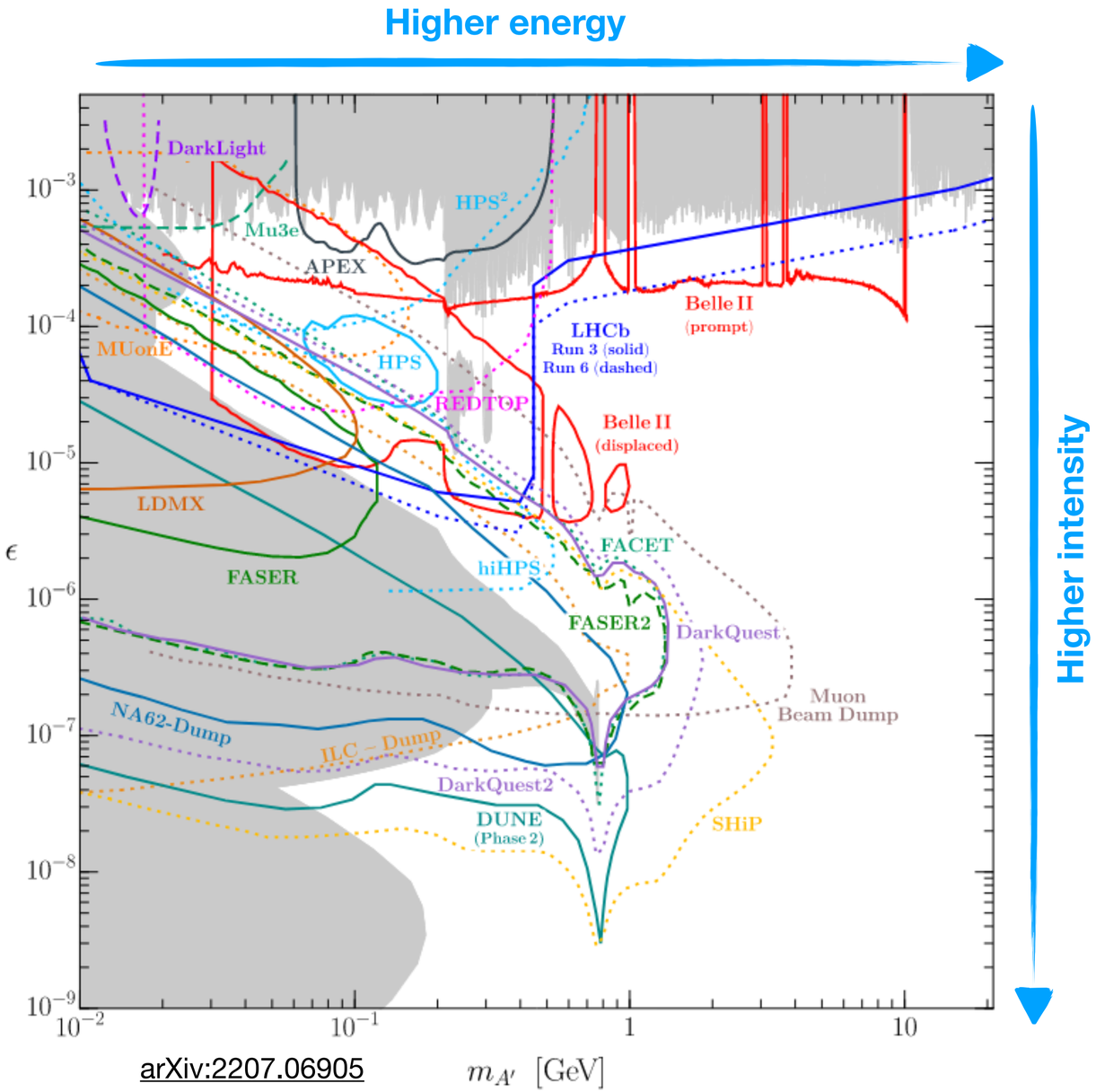


Kinetic mixing strength

Dark photon mass

arXiv:2207.06905

Dark Photons: Current Limits

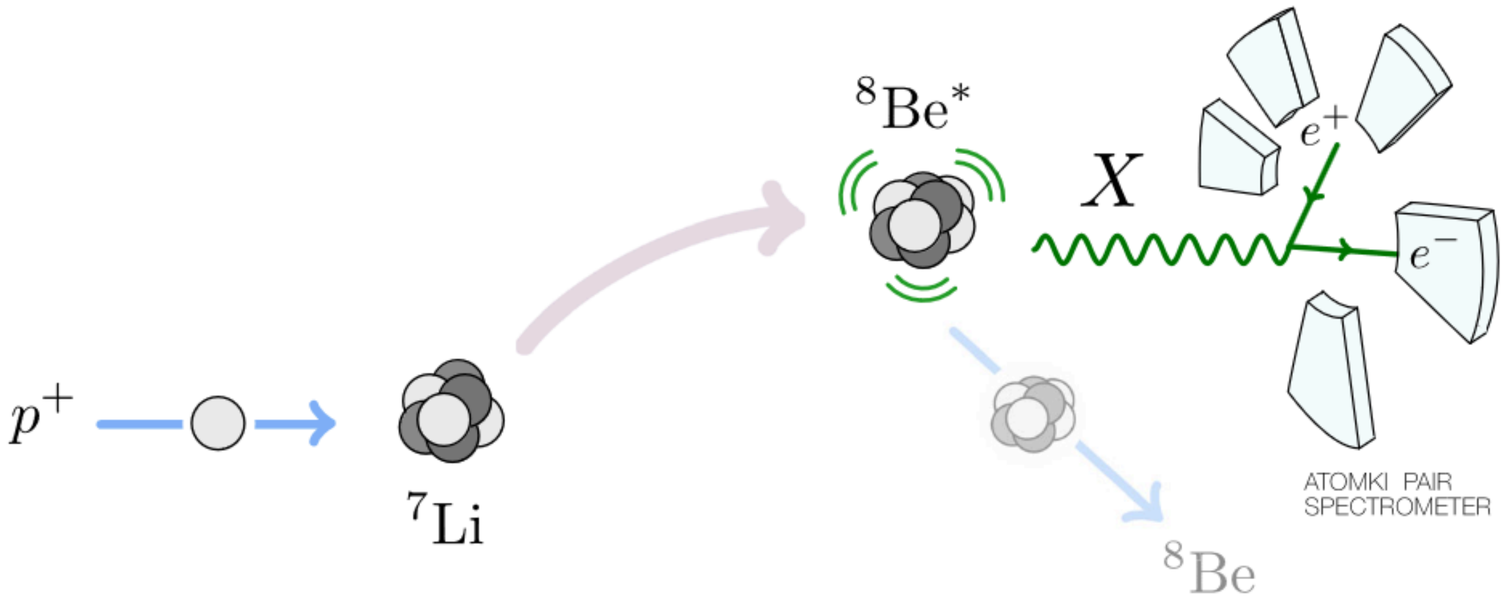


arXiv:2207.06905

- Larger experiments like ATLAS and CMS needed to probe energy frontier
- Smaller (usually beam dump) experiments required to probe lower coupling strengths and lower masses
- Interesting physics to be done even without a large budget

Experimental Anomalies: X17

- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be



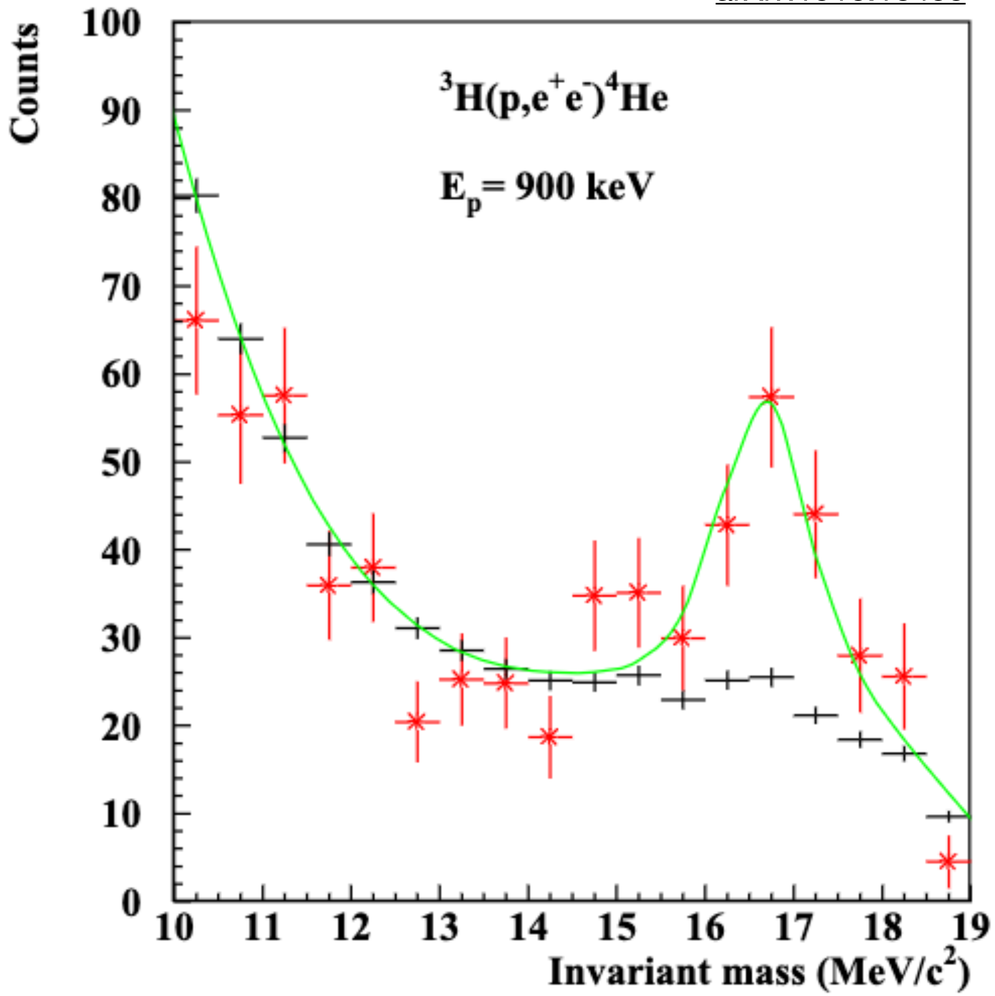
Physical Review D 95, 035017 (2017)

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:2311.18632, arXiv:2401.11676

Experimental Anomalies: X17

- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be
- Excess in $e^{+}e^{-}$ invariant mass spectrum
- Similar anomaly observed in ^{4}He and ^{12}C

arXiv:1910.10459

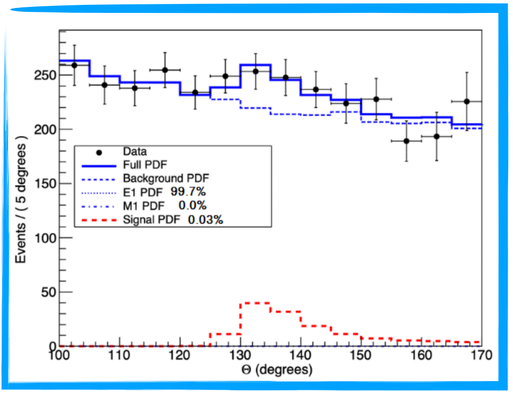


See: Phys. Rev. Lett. 116, 042501 (2016), arXiv:1910.10459, Phys. Rev. C 104, 044003 (2021), arXiv:2205.07744, Phys. Rev. C 106, L061601 (2022), arXiv:2308.06473, arXiv:2311.18632, arXiv:2401.11676

Experimental Anomalies: X17?

- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be
- Excess in e^+e^- invariant mass spectrum
- Similar anomaly observed in ^{4}He and ^{12}C

Positive Observations



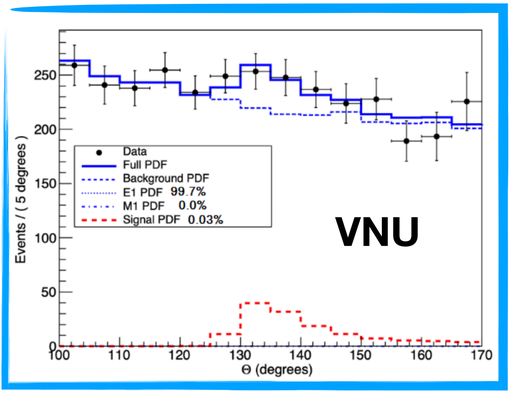
VNU University of Science in Vietnam (arXiv:2401.1176): independent two arm spectrometer, with help from ATOMKI collaboration, 4σ excess

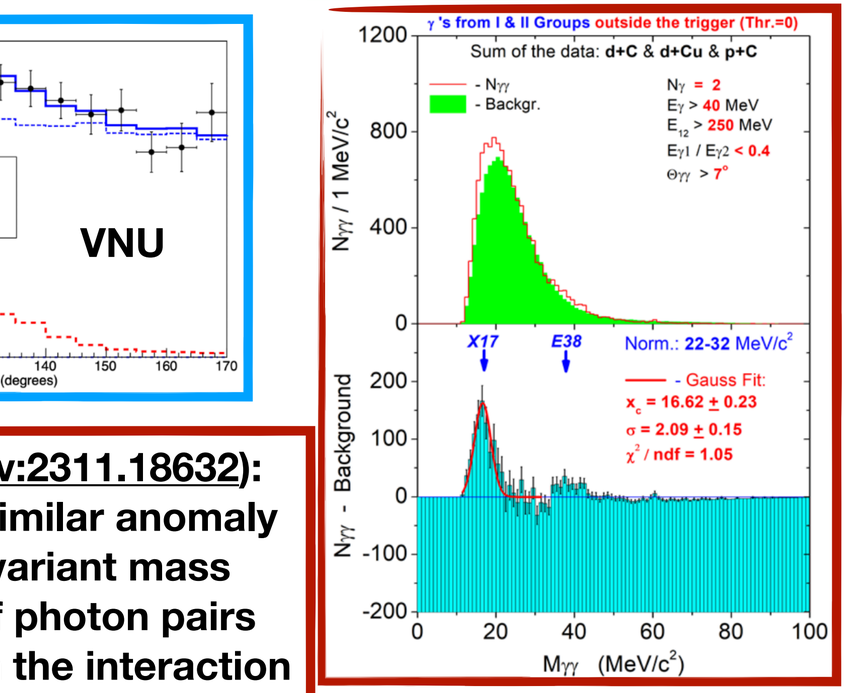
Negative Observations

Experimental Anomalies: X17?

- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be
- Excess in e^+e^- invariant mass spectrum
- Similar anomaly observed in ^{4}He and ^{12}C

Positive Observations





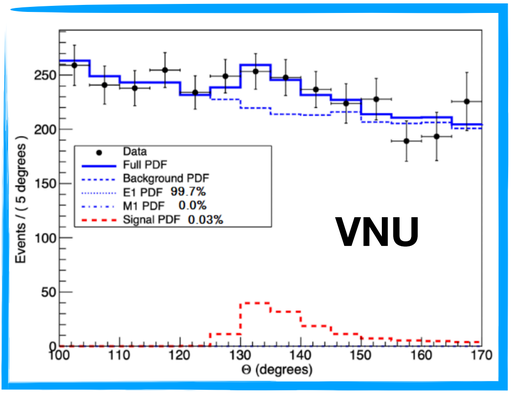
JINR (arXiv:2311.18632): observed similar anomaly in the invariant mass spectra of photon pairs produced in the interaction of protons and deuterons with carbon and copper nuclei

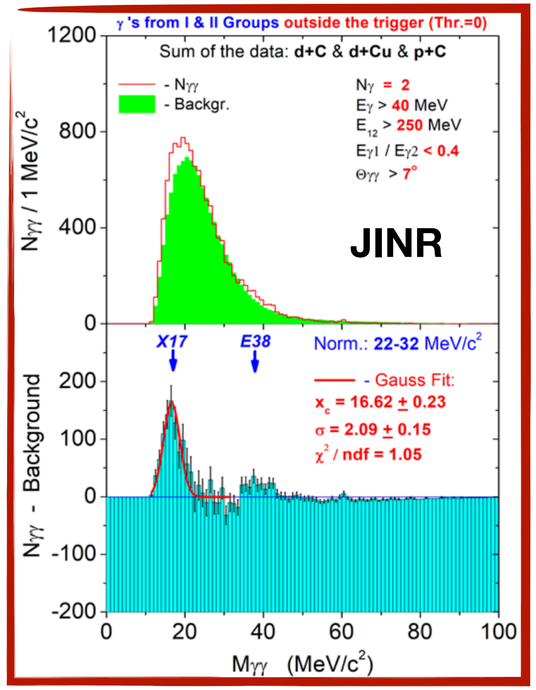
Negative Observations

Experimental Anomalies: X17?

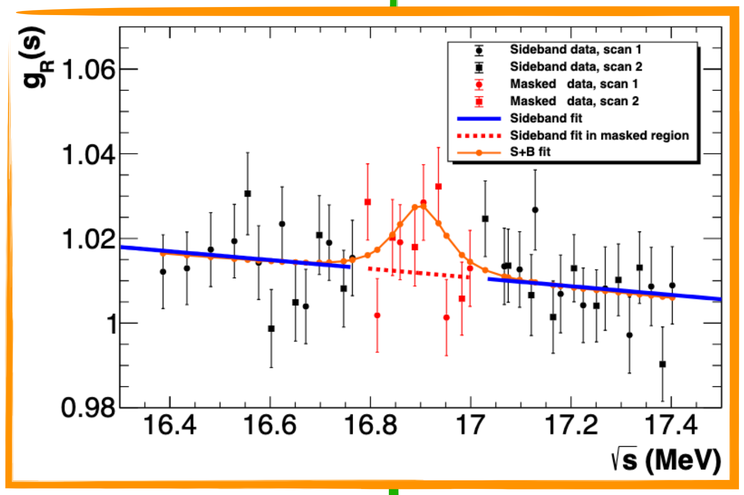
- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be
- Excess in e^+e^- invariant mass spectrum
- Similar anomaly observed in ^{4}He and ^{12}C

Positive Observations





Negative Observations

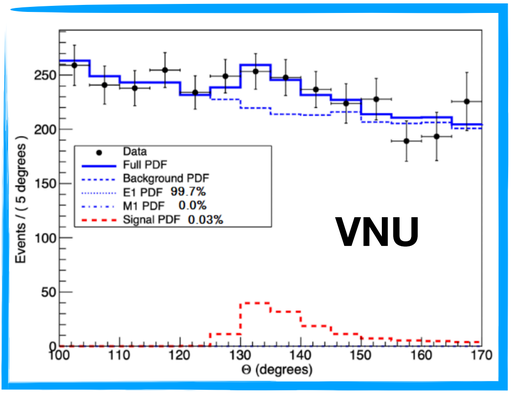


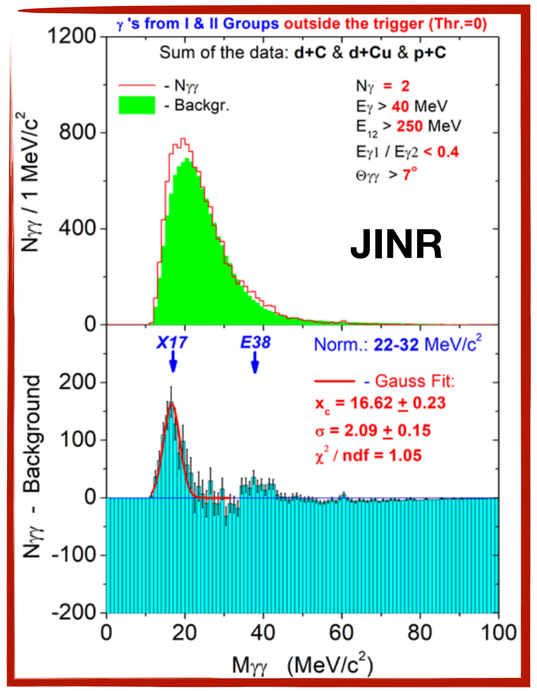
PADME at INFN (arXiv:2505.24797): positron beam on fixed target, see roughly 2σ significance over background

Experimental Anomalies: X17?

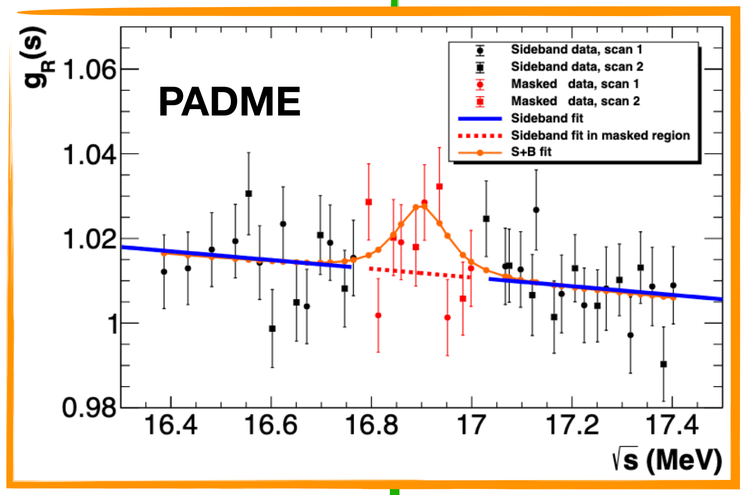
- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be
- Excess in e^+e^- invariant mass spectrum
- Similar anomaly observed in ^{4}He and ^{12}C

Positive Observations

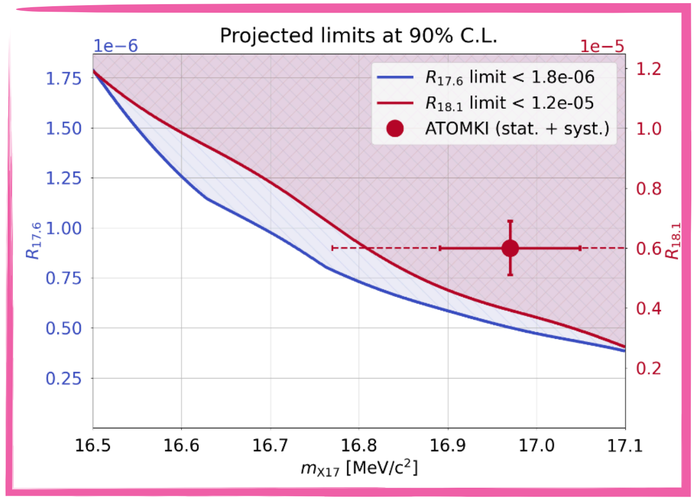




Negative Observations



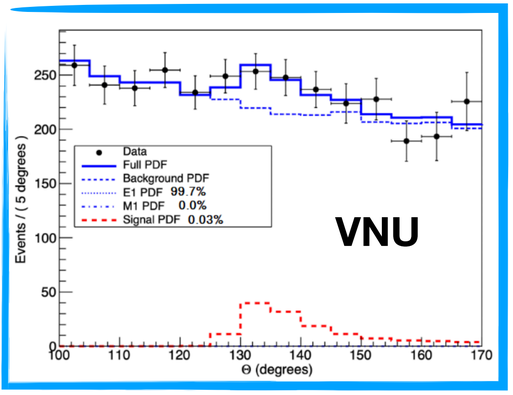
MEGII at PSI (arXiv:2411.07994): protons on a Li target, no significant signal

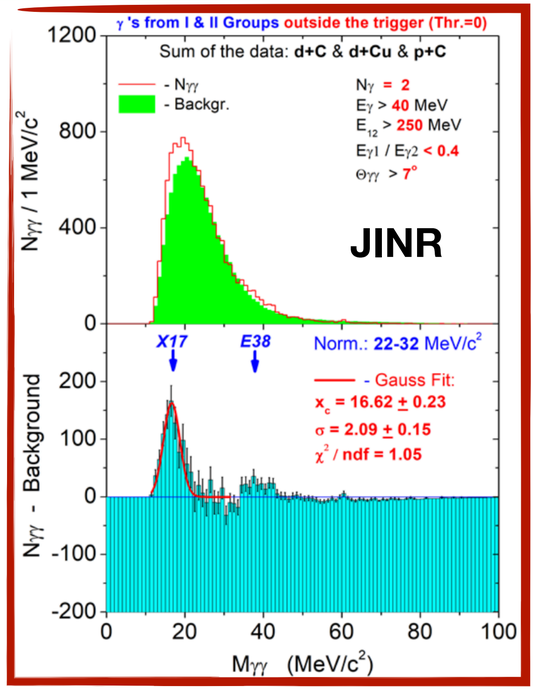


Experimental Anomalies: X17?

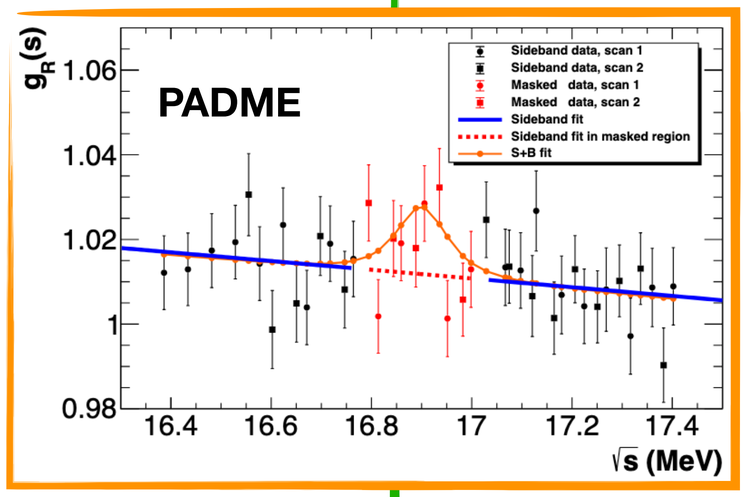
- Originally observed by the ATOMKI collaboration in excited states of ^{8}Be
- Excess in e^+e^- invariant mass spectrum
- Similar anomaly observed in ^{4}He and ^{12}C

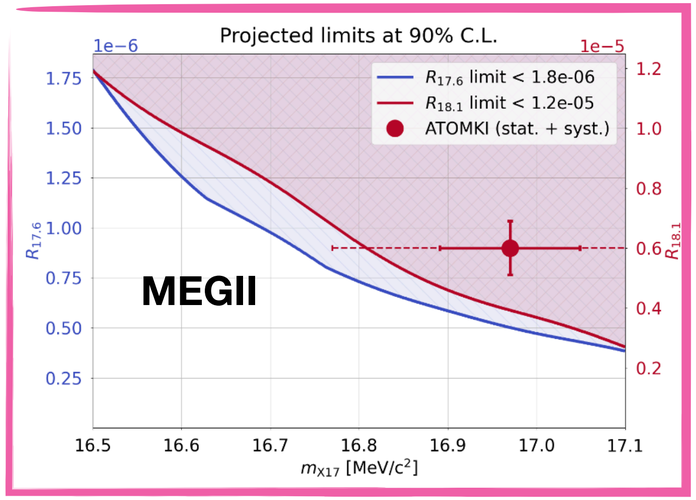
Positive Observations





Negative Observations

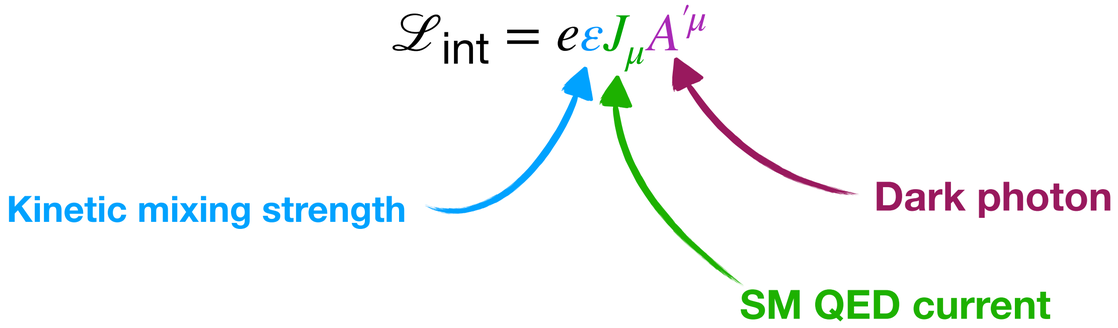




More exploring to be done

X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

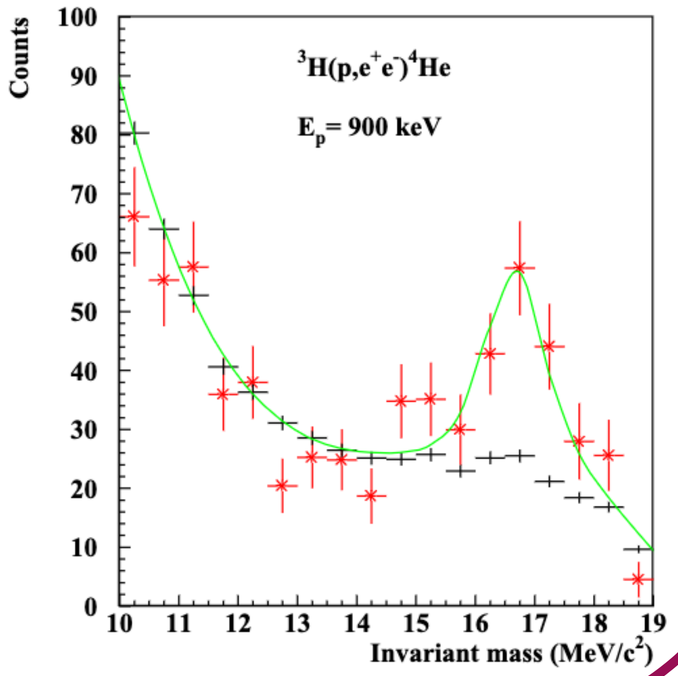


For more details see: Feng et. al. PRL 117, 071803 (2016), Physical Review D 95, 035017 (2017), Physical Review D 102, 036016 (2020)

X17: Protophobic Gauge Boson?

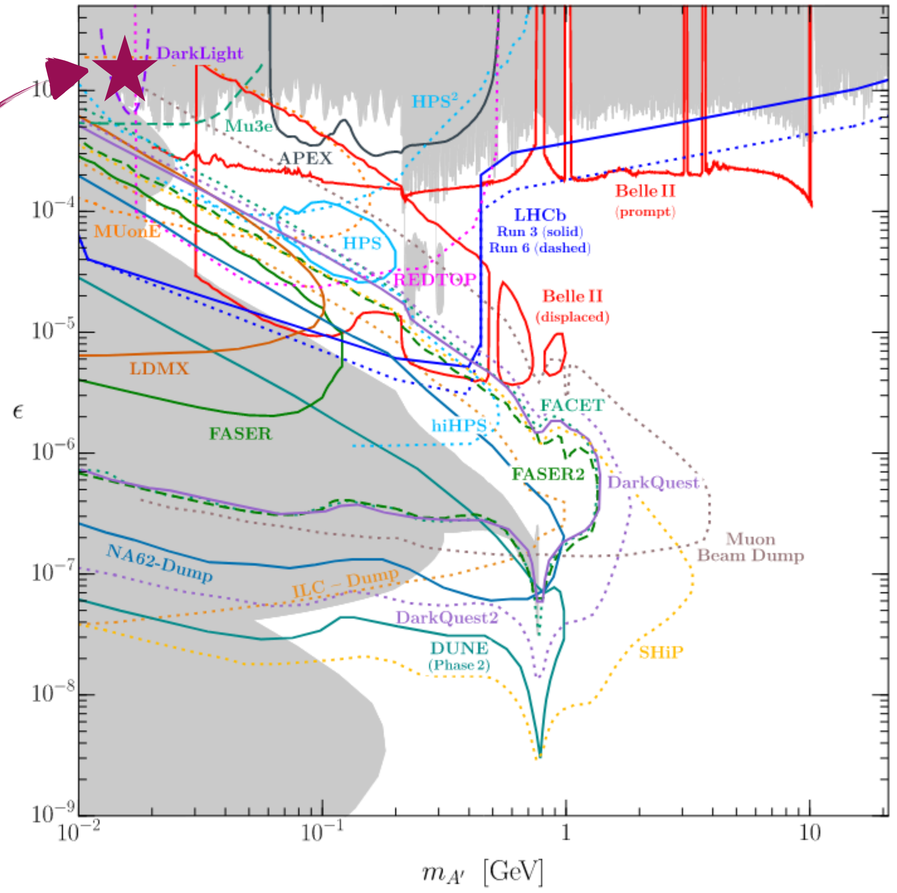
- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

If the X17 was a standard dark photon…



$\Rightarrow \varepsilon \approx 10^{-3}$

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



Already excluded!

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

X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

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

Make it more general

$$\mathscr{L}_{\text{int}} = e \sum_f \varepsilon_f \bar{f} \gamma_\mu f X^\mu$$

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

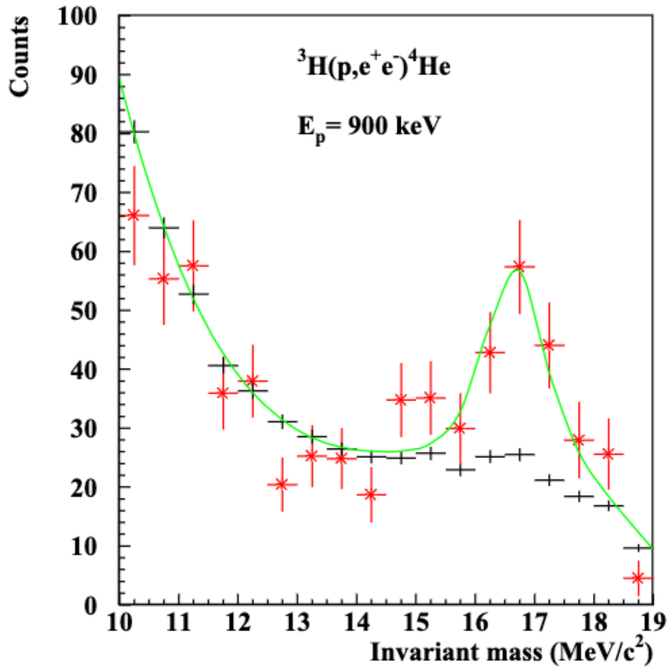
X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

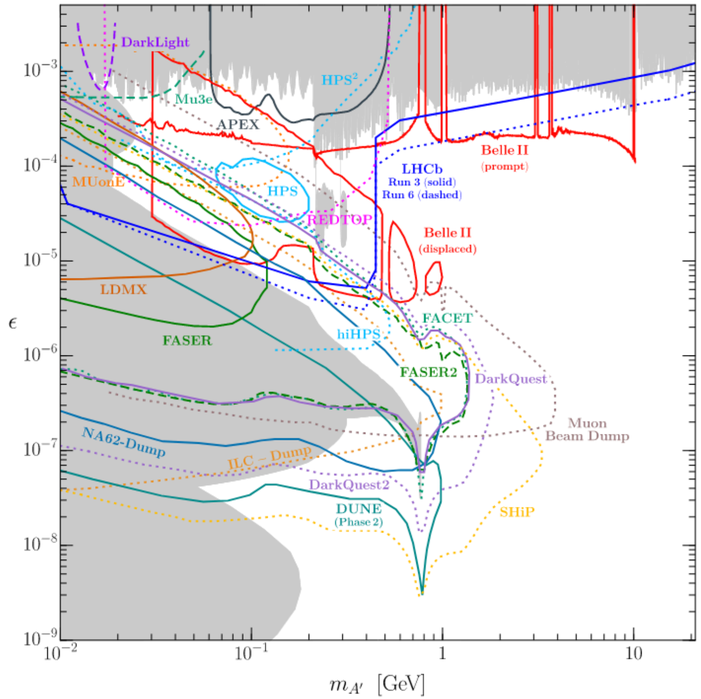
~~$\mathscr{L}_{\text{int}} = e\epsilon J_\mu A'^\mu$~~

Make it more general

$$\mathscr{L}_{\text{int}} = e\sum_f \varepsilon_f \bar{f}\gamma_\mu f X^\mu$$



+



$\Rightarrow \varepsilon_u < \varepsilon_d$ and $\varepsilon_p \ll \varepsilon_n$

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

X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

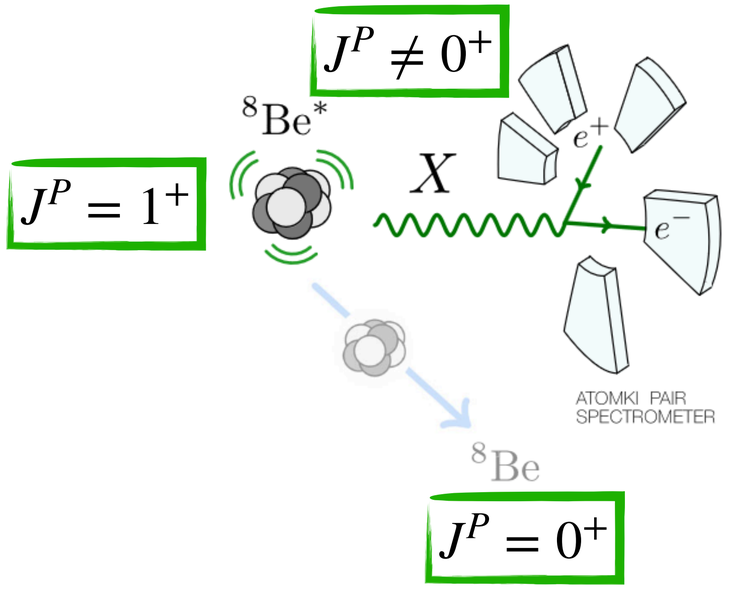
~~$\mathscr{L}_{\text{int}} = \varepsilon e J_\mu A'^\mu$~~

Make it more general

$$\mathscr{L}_{\text{int}} = e \sum_f \varepsilon_f \bar{f} \gamma_\mu f X^\mu$$

$\Rightarrow \varepsilon_u < \varepsilon_d$ and $\varepsilon_p \ll \varepsilon_n$

- Can anything be said about what kind of boson?
  - Scalar
  - Pseudoscalar
  - Axial vector
  - Vector



X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

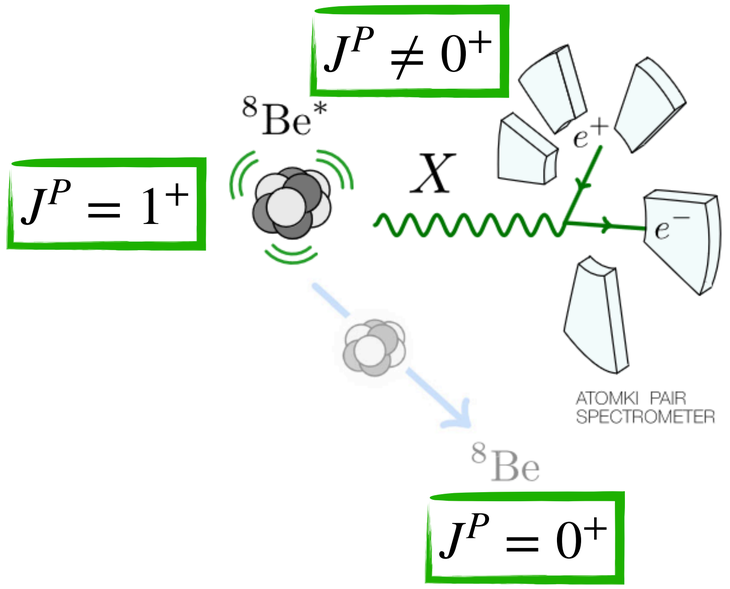
~~$\mathscr{L}_{\text{int}} = \varepsilon e J_\mu A'^\mu$~~

Make it more general

$$\mathscr{L}_{\text{int}} = e \sum_f \varepsilon_f \bar{f} \gamma_\mu f X^\mu$$

$\Rightarrow \varepsilon_u < \varepsilon_d$ and $\varepsilon_p \ll \varepsilon_n$

- Can anything be said about what kind of boson?
  - ~~Scalar~~
  - Pseudoscalar
  - Axial vector
  - Vector



X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

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

Make it more general

$$\mathscr{L}_{\text{int}} = e \sum_f \varepsilon_f \bar{f} \gamma_\mu f X^\mu$$

$$\Rightarrow \varepsilon_u < \varepsilon_d \text{ and } \varepsilon_p \ll \varepsilon_n$$

- Can anything be said about what kind of boson?
  - ~~Scalar~~
  - ~~Pseudoscalar~~
  - Axial vector
  - Vector

X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

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

Make it more general

$$\mathscr{L}_{\text{int}} = e \sum_f \varepsilon_f \bar{f} \gamma_\mu f X^\mu$$

$$\Rightarrow \varepsilon_u < \varepsilon_d \text{ and } \varepsilon_p \ll \varepsilon_n$$

- Can anything be said about what kind of boson?
  - ~~Scalar~~
  - ~~Pseudoscalar~~
  - Axial vector
  - Vector

Generally favoured by observation of X17, but…

X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

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

Make it more general

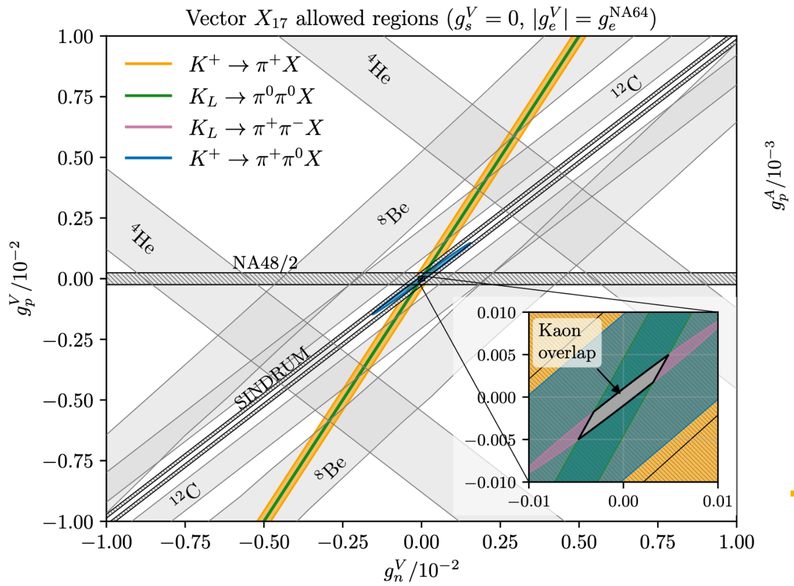
$$\mathscr{L}_{\text{int}} = e\sum_f \varepsilon_f \bar{f}\gamma_\mu f X^\mu$$

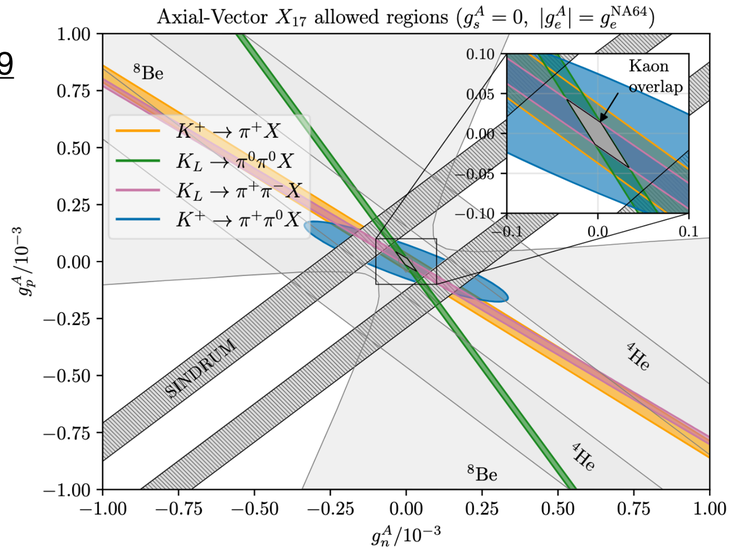
$\Rightarrow \varepsilon_u < \varepsilon_d$ and $\varepsilon_p \ll \varepsilon_n$

- Can anything be said about what kind of boson?
  - ~~Scalar~~
  - ~~Pseudoscalar~~
  - Axial vector
  - Vector

Generally favoured by observation of X17, but…

Hostert, Pospelov, Thompson: arXiv:2602.19479





…tension with, in particular, ^{12}C and existing Kaon experiment limits

X17: Protophobic Gauge Boson?

- Potential explanation: dark gauge boson with a **protophobic** coupling to the SM

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

Make it more general

$$\mathscr{L}_{\text{int}} = e\sum_f \varepsilon_f \bar{f}\gamma_\mu f X^\mu$$

$\Rightarrow \varepsilon_u < \varepsilon_d$ and $\varepsilon_p \ll \varepsilon_n$

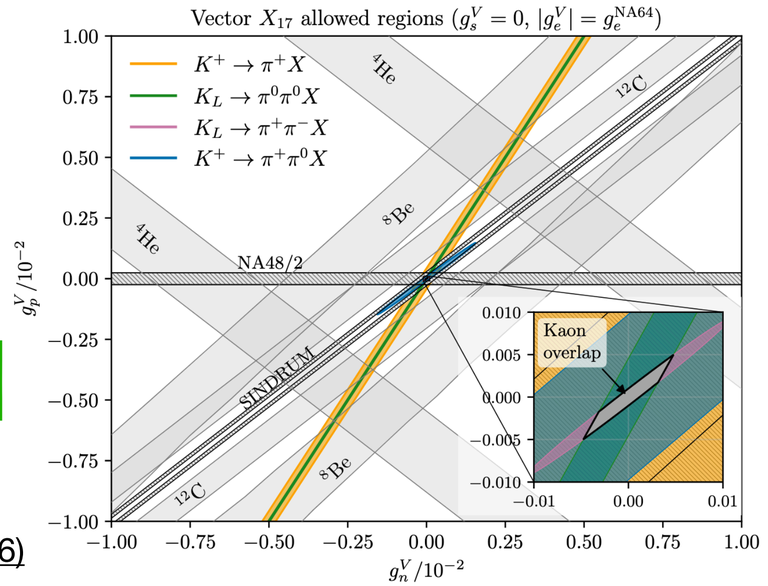
- Can anything be said about what kind of boson?
  - ~~Scalar~~
  - ~~Pseudoscalar~~
  - Axial vector
  - Vector

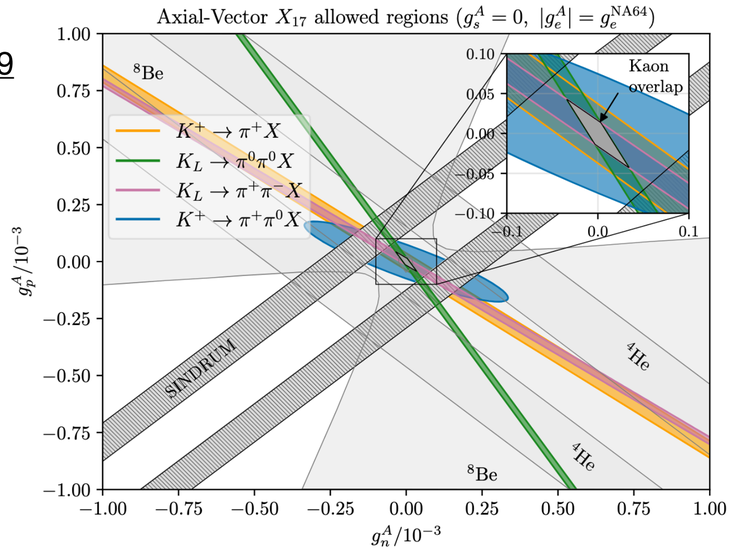
Generally favoured by observation of X17, but…

Theoretical explanations still being developed

For more information:
Community Report: Shedding light on X17 (2023)
ECT* Workshop: The X17 particle, status, and new ideas (2026)

Hostert, Pospelov, Thompson: arXiv:2602.19479

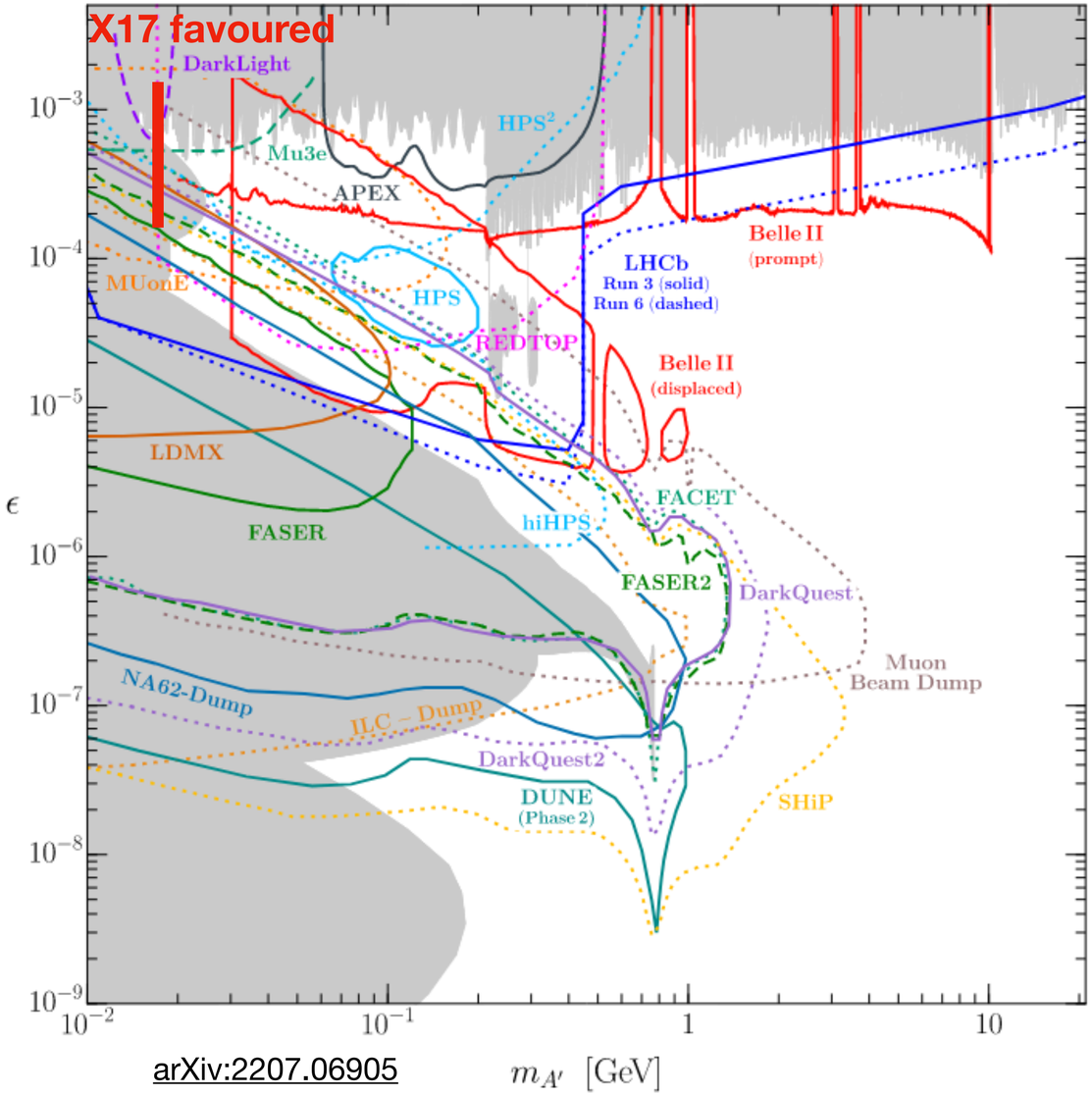




…tension with, in particular, ^{12}C and existing Kaon experiment limits

Probing the X17 Favoured Parameter Space

Limits for past (grey) and future dark photon experiments

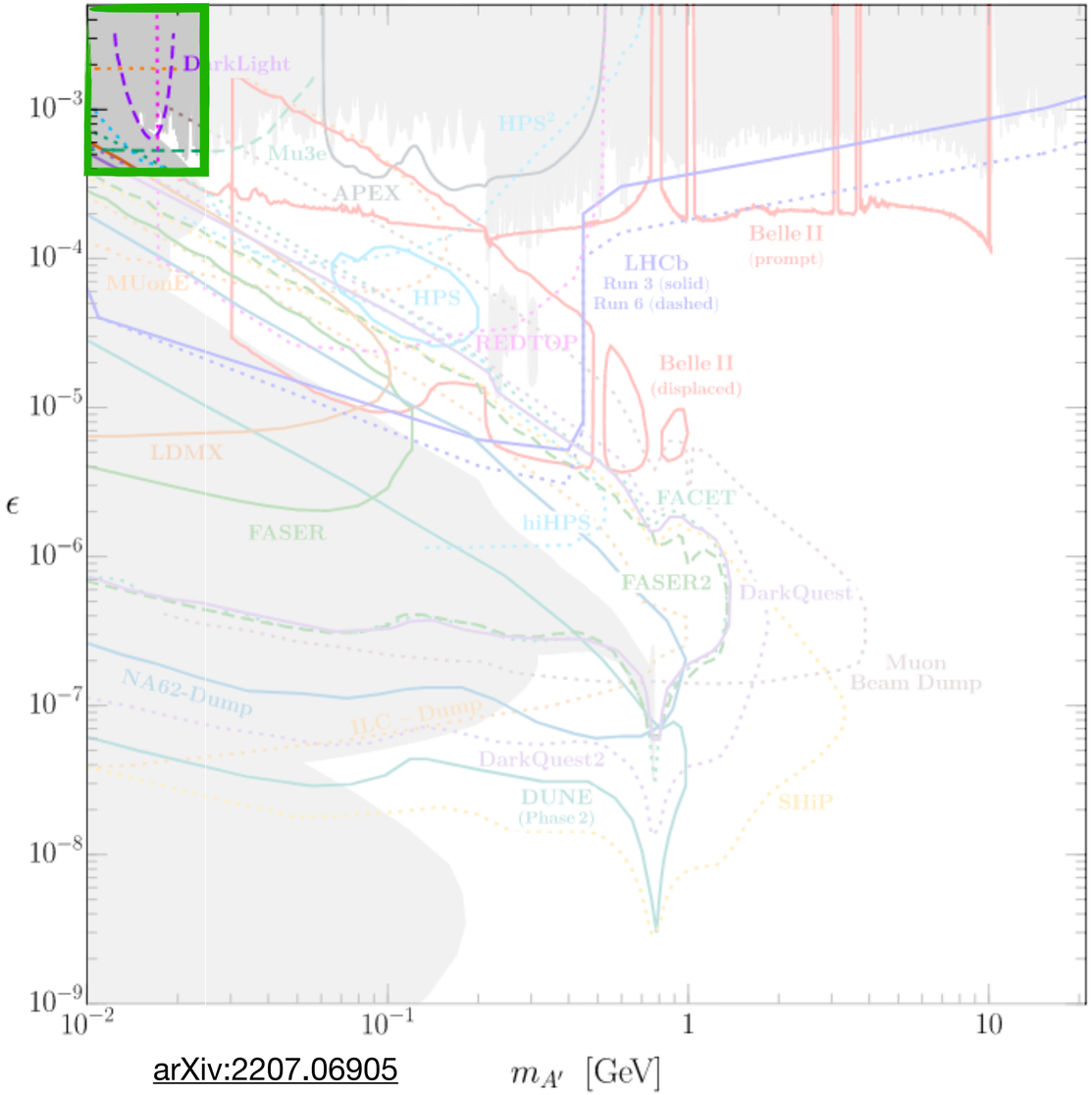


arXiv:2207.06905

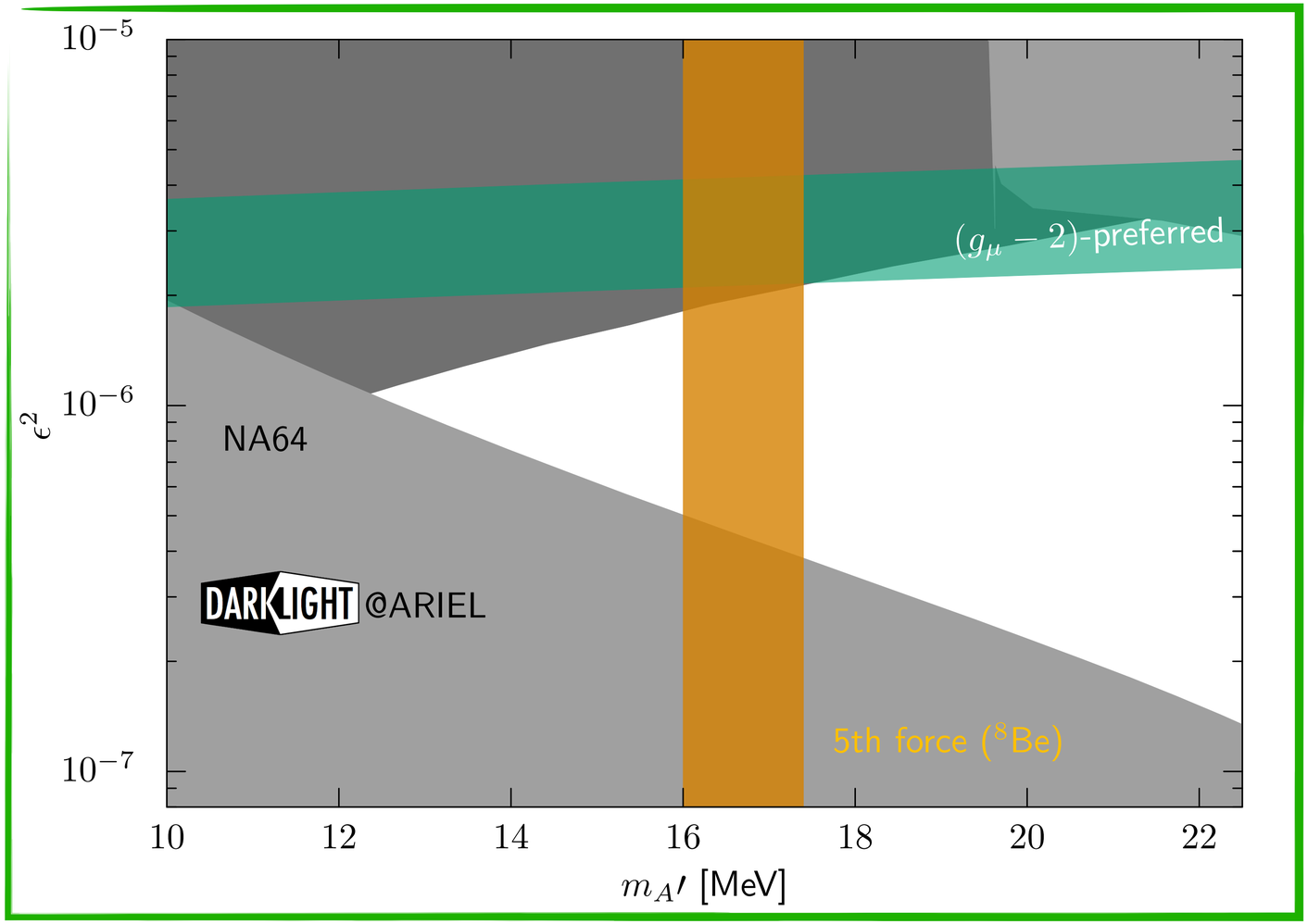
- Protophobic coupling means we have strayed from the standard dark photon model
  - Can still show limits in the same parameter space
- Main consequence of protophobic coupling: suppressed coupling to pions
  - Reopens some previously excluded parameter space

Probing the X17 Favoured Parameter Space

Limits for past (grey) and future dark photon experiments

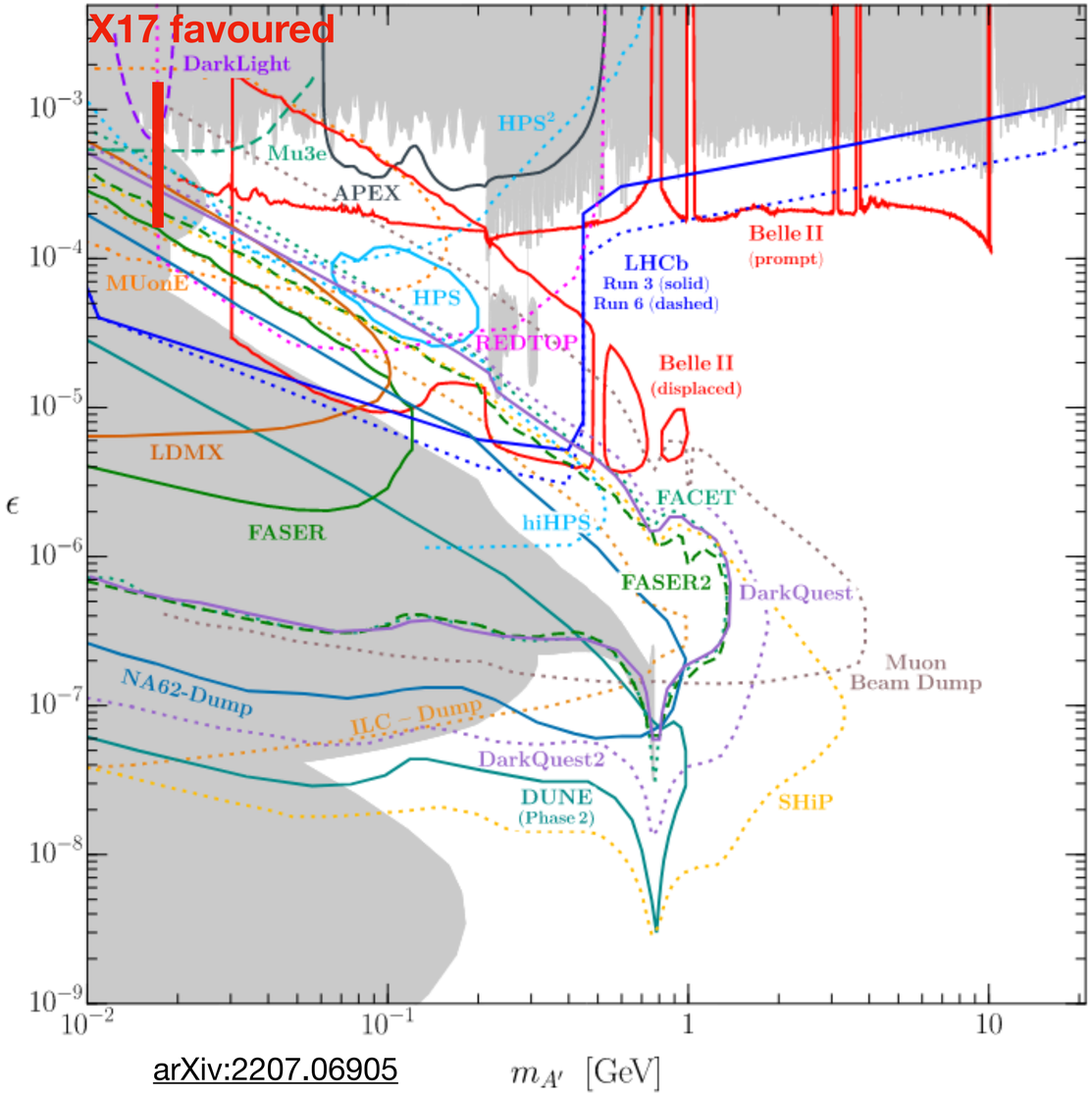


arXiv:2207.06905



Probing the X17 Favoured Parameter Space

Limits for past (grey) and future dark photon experiments



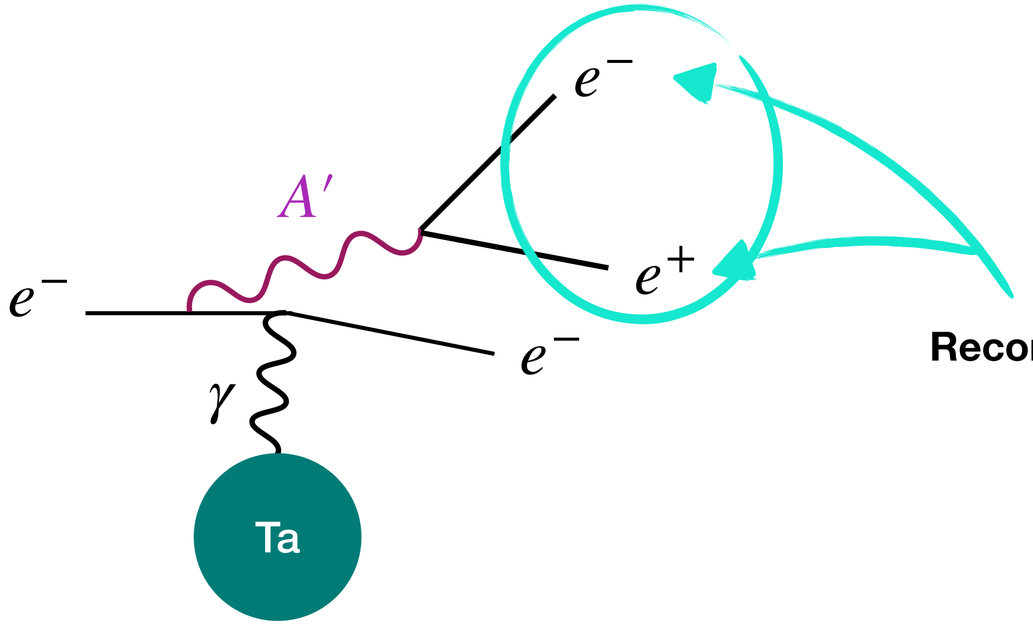
arXiv:2207.06905

- Protophobic coupling means we have strayed from the standard dark photon model
  - Can still show limits in the same parameter space
- Main consequence of protophobic coupling: suppressed coupling to pions
  - Reopens some previously excluded parameter space
- Can only be probed with a fully leptonic experiment

DARKLIGHT

DarkLight@ARIEL

- Bombard fixed high Z target with low energy high intensity electron beam



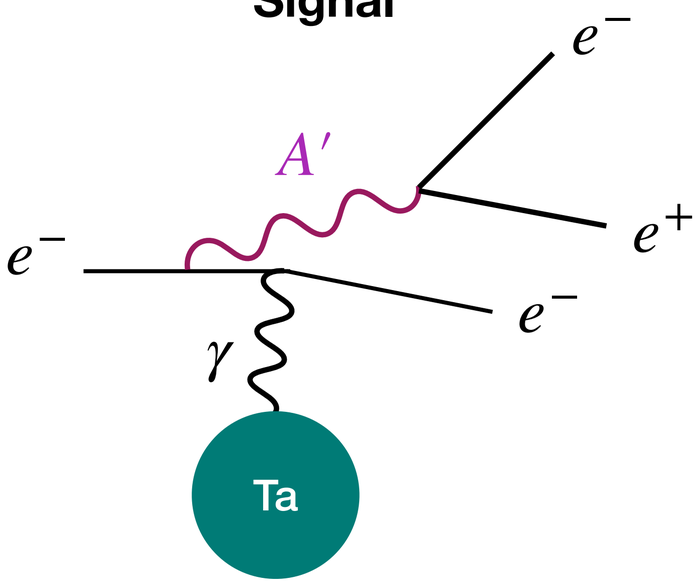
Reconstruct invariant mass of electron-positron system

- Low energy allows probe of X17 favoured region, high intensity for lots of statistics

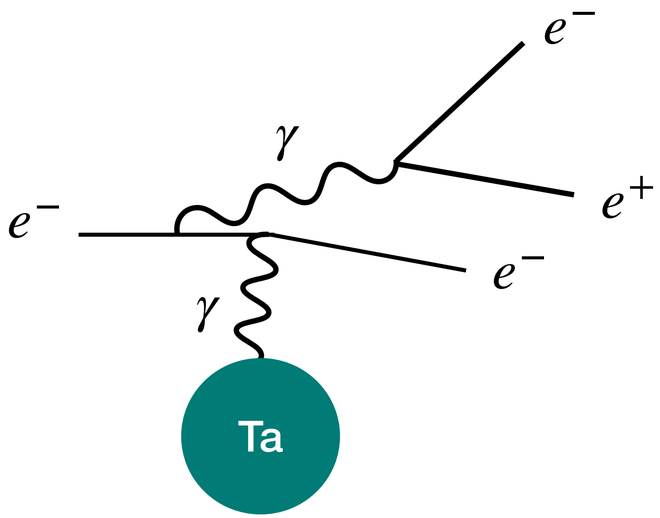
Signal and Background

- Two main background processes to consider:

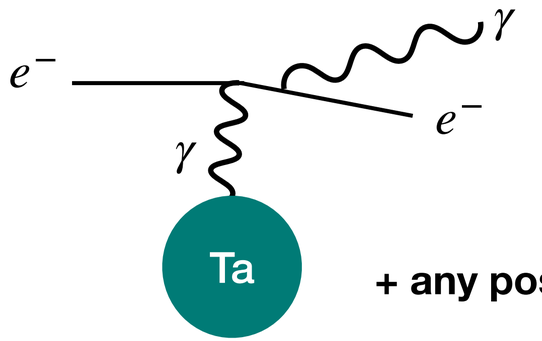
Signal



Irreducible background



Reducible background

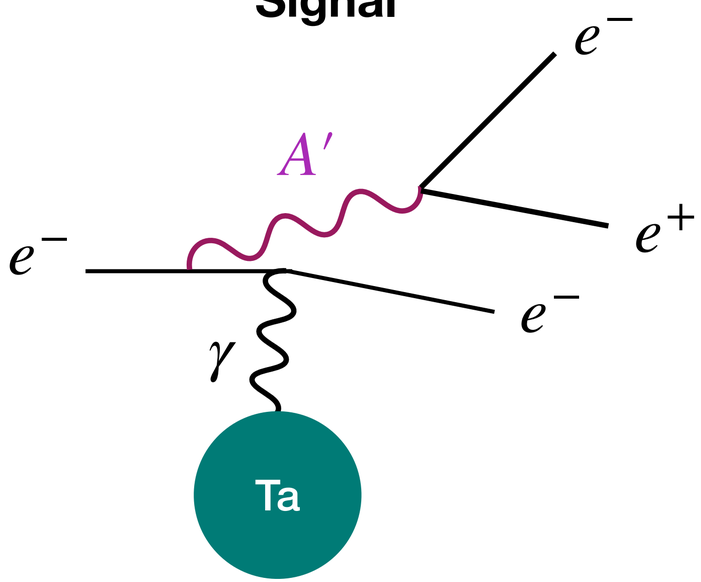


+ any positron

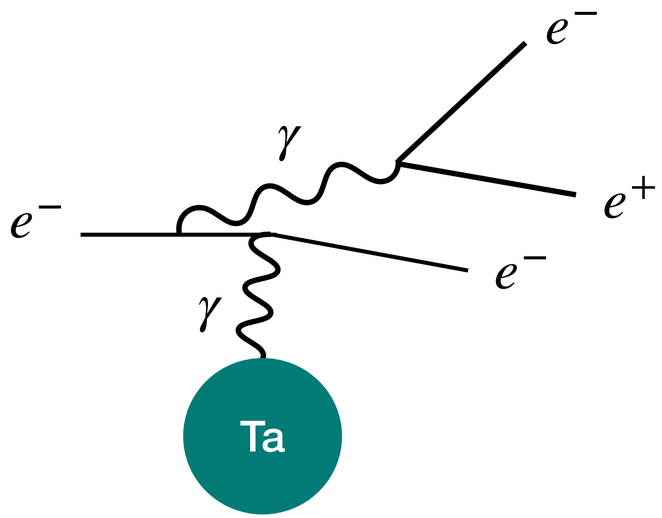
Signal and Background

- Two main background processes to consider:

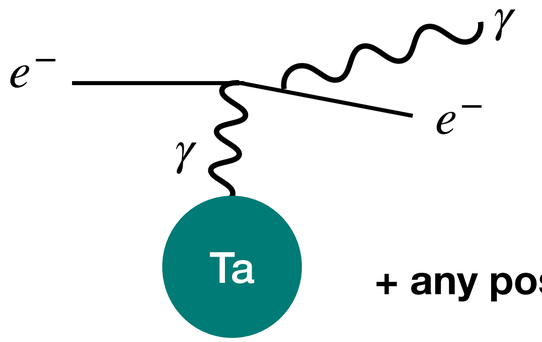
Signal



Irreducible background



Reducible background

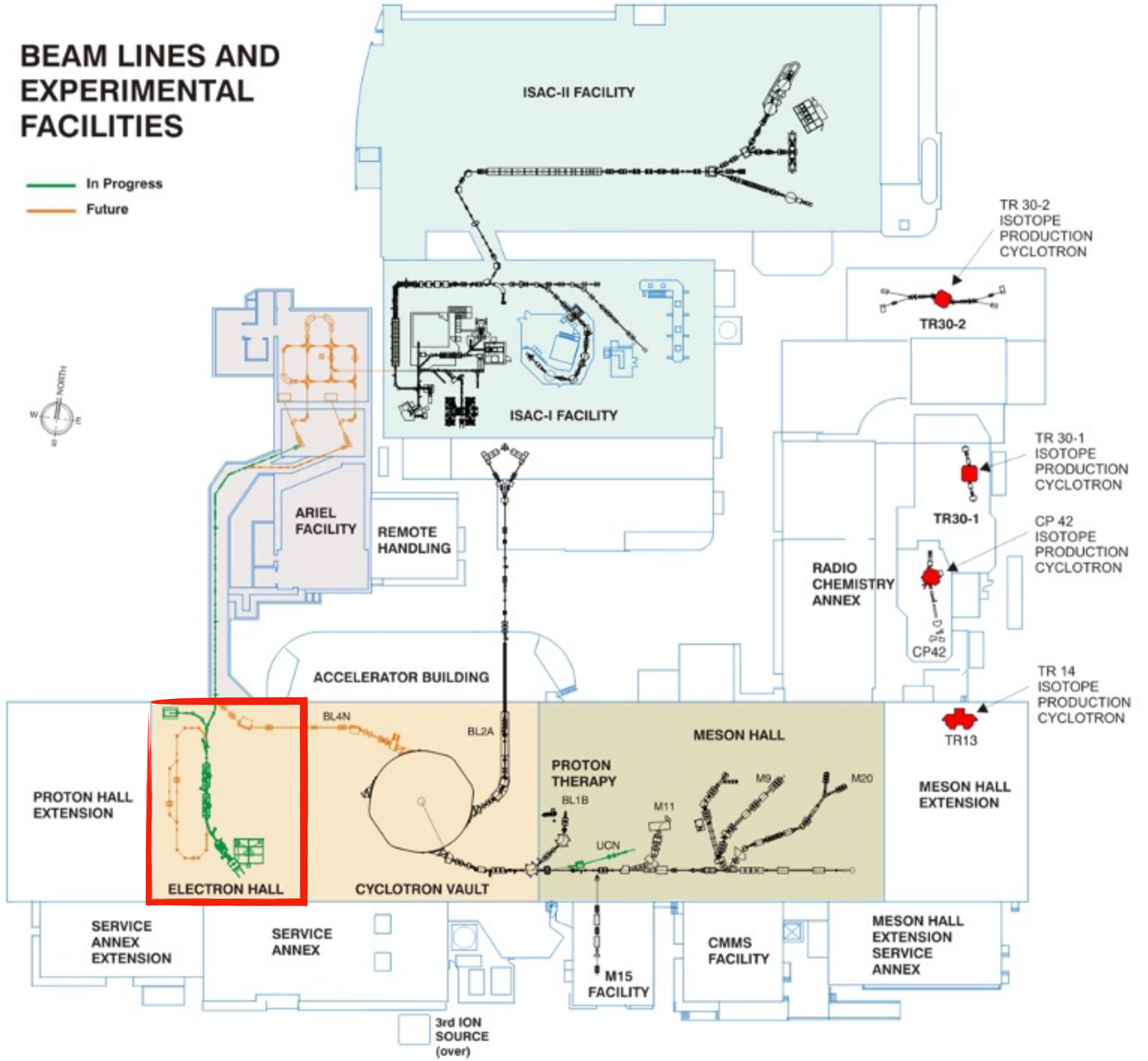


+ any positron

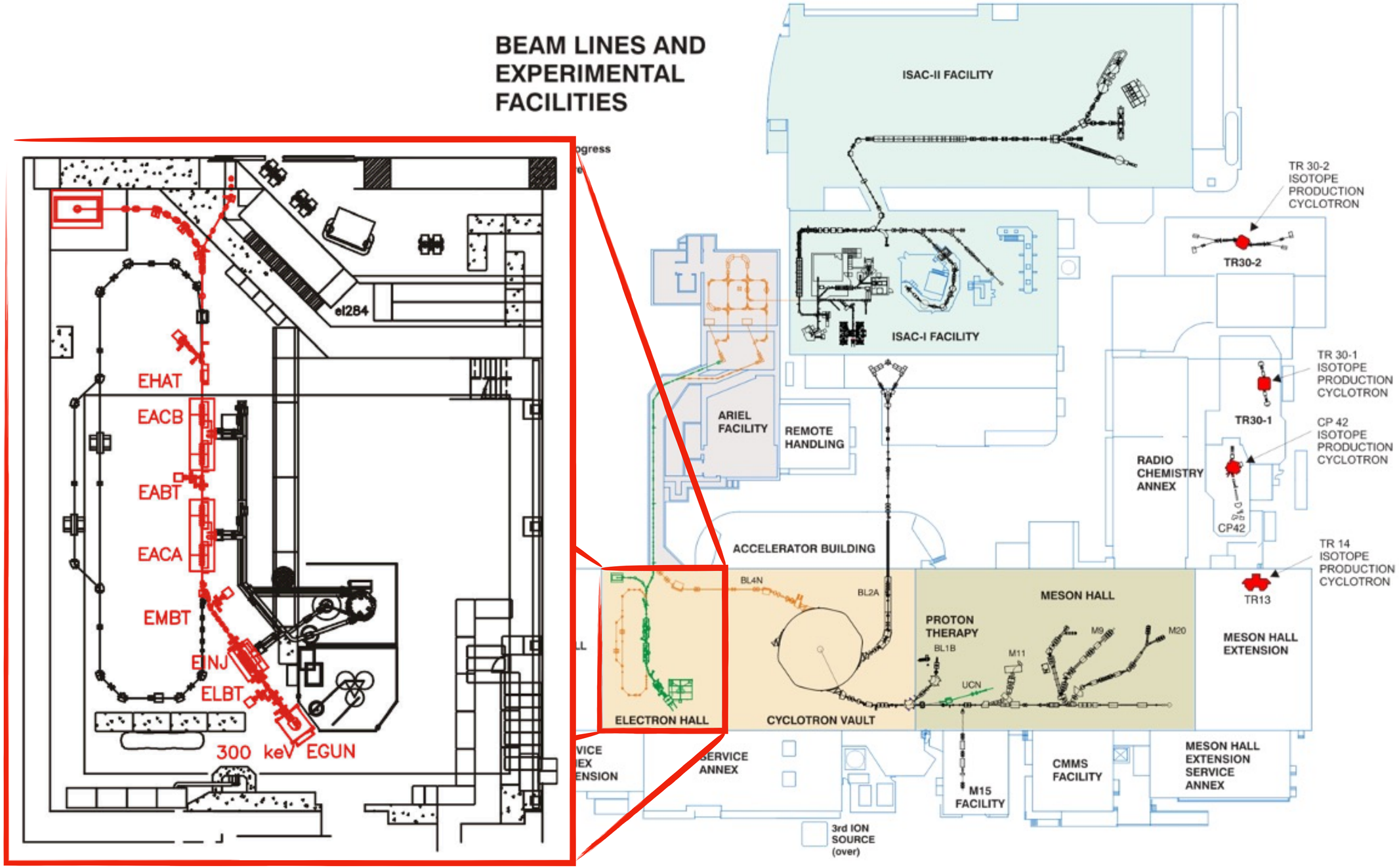
- Carefully select electron and positron momenta using the spectrometer magnets and arm angles to maximize signal
- Put very strict coincidence condition on the trigger

ARIEL

- **A**dvanced **R**are **I**sotop**E** **L**aboratory
- New facility to be operational in 2027

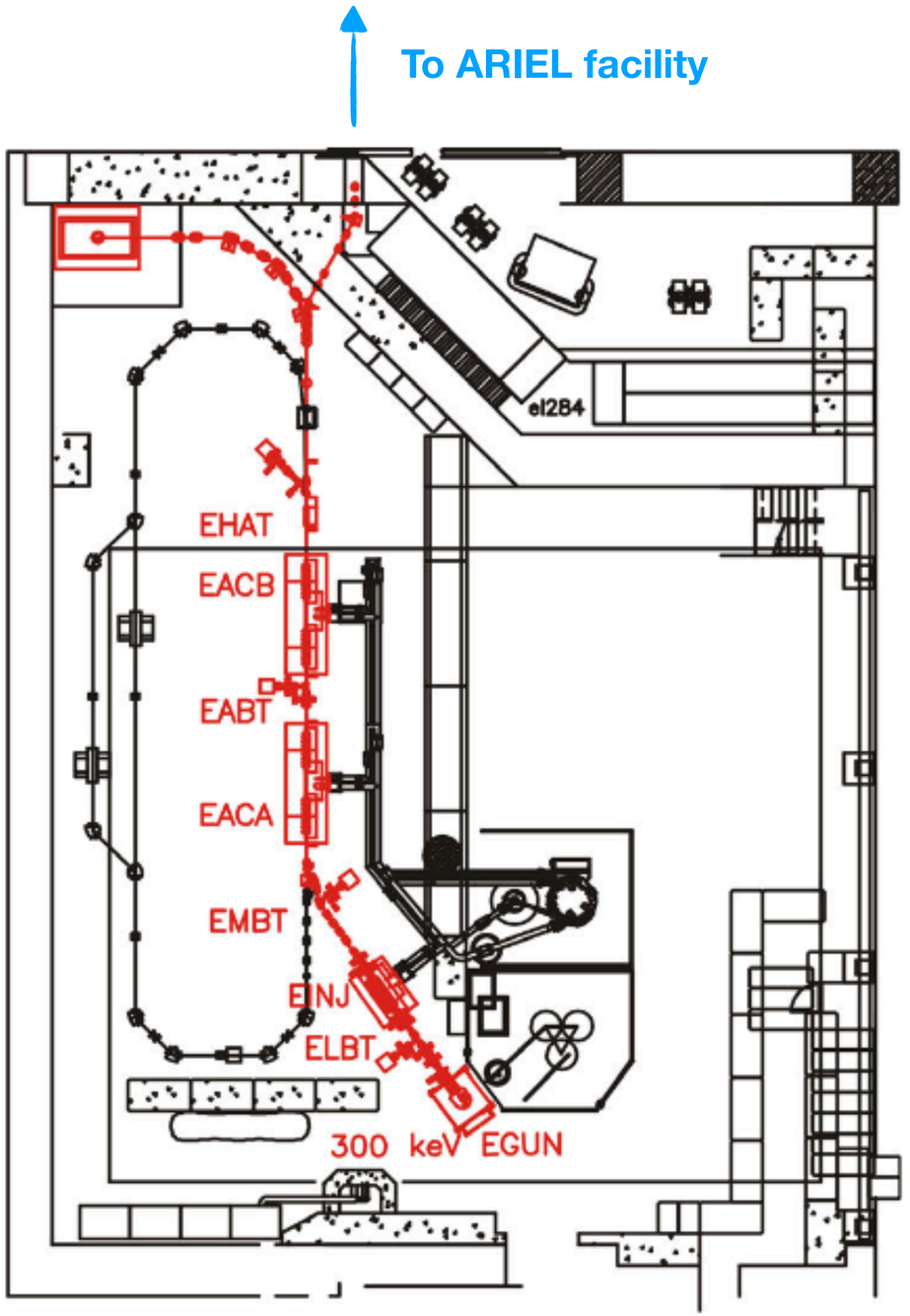


ARIEL


BEAM LINES AND EXPERIMENTAL FACILITIES
ISAC-II FACILITY
ISAC-I FACILITY
TR 30-2 ISOTOPE PRODUCTION CYCLOTRON
TR30-2
TR 30-1 ISOTOPE PRODUCTION CYCLOTRON
TR30-1
CP 42 ISOTOPE PRODUCTION CYCLOTRON
CP42
ARIEL FACILITY
REMOTE HANDLING
RADIO CHEMISTRY ANNEX
ACCELERATOR BUILDING
TR 14 ISOTOPE PRODUCTION CYCLOTRON
TR13
MESON HALL
PROTON THERAPY
MESON HALL EXTENSION
BL4N
BL2A
BL1B
M11
M9
M20
UCN
ELECTRON HALL
CYCLOTRON VAULT
SERVICE ANNEX
CMMS FACILITY
M15 FACILITY
MESON HALL EXTENSION SERVICE ANNEX
3rd ION SOURCE (over)
el284
EHAT
EACB
EABT
EACA
EMBT
EINJ
ELBT
300 keV EGUN

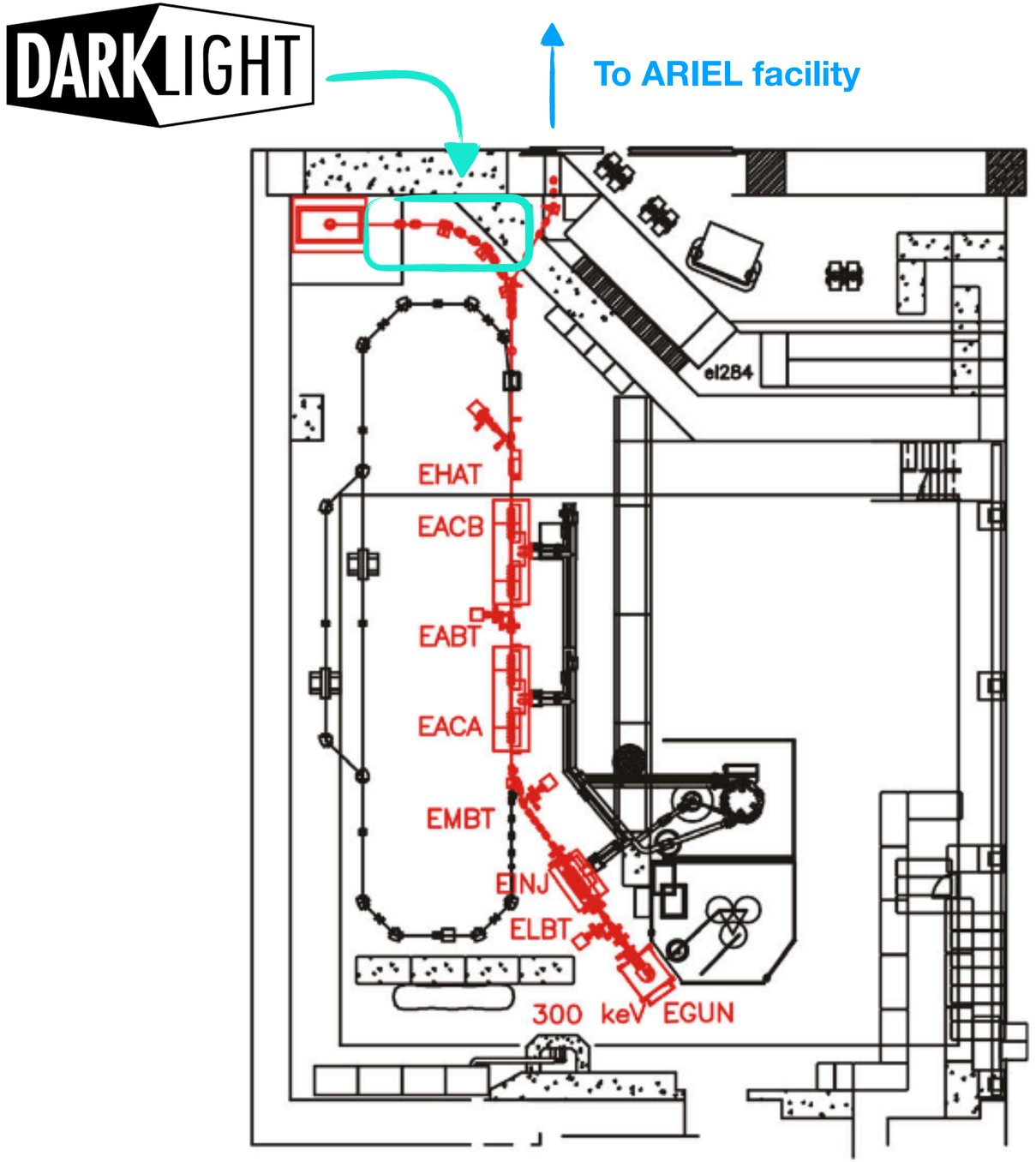
ARIEL eLinac

- 30 MeV electron beam setup



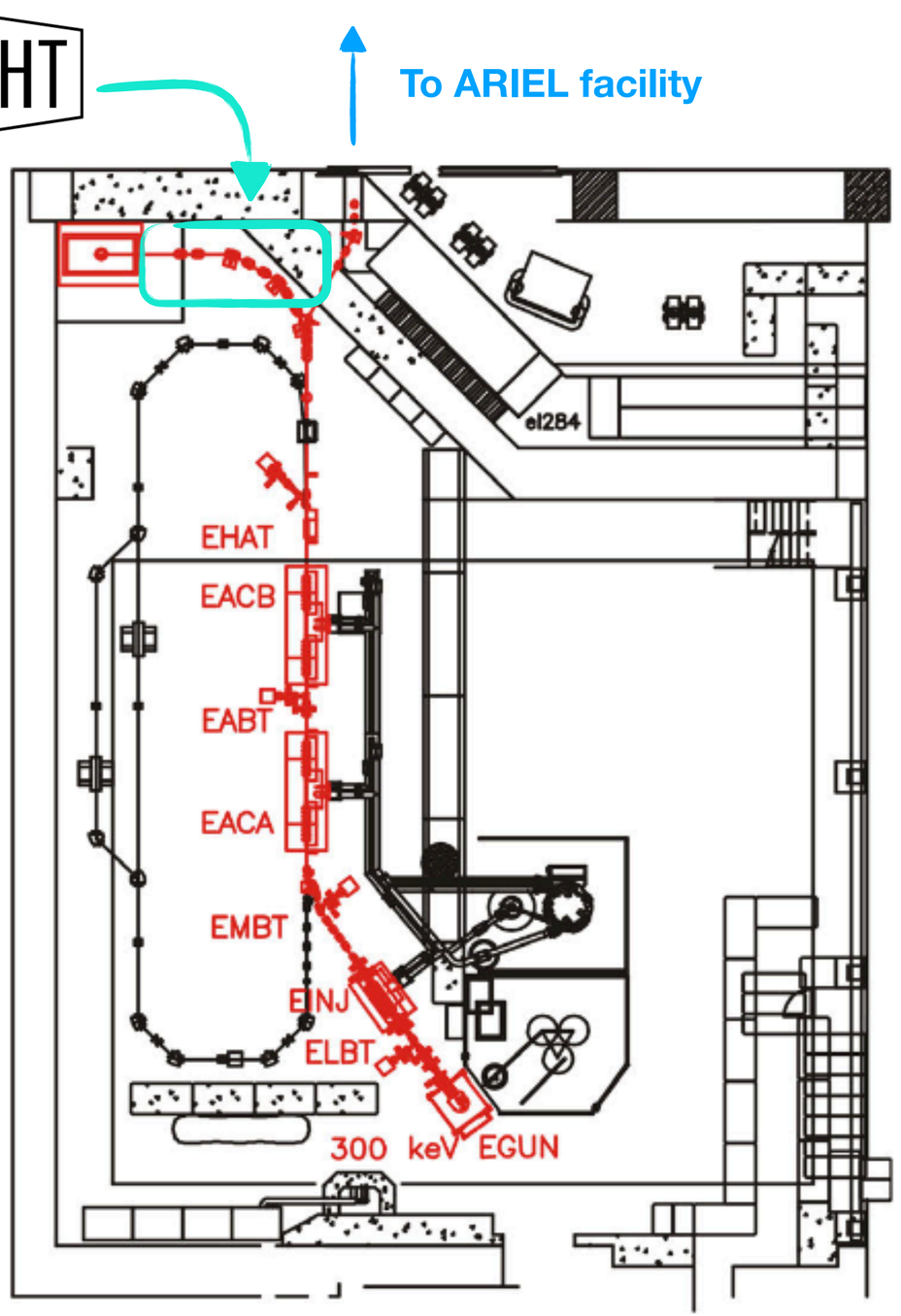
ARIEL eLinac

- 30 MeV electron beam setup



ARIEL eLinac

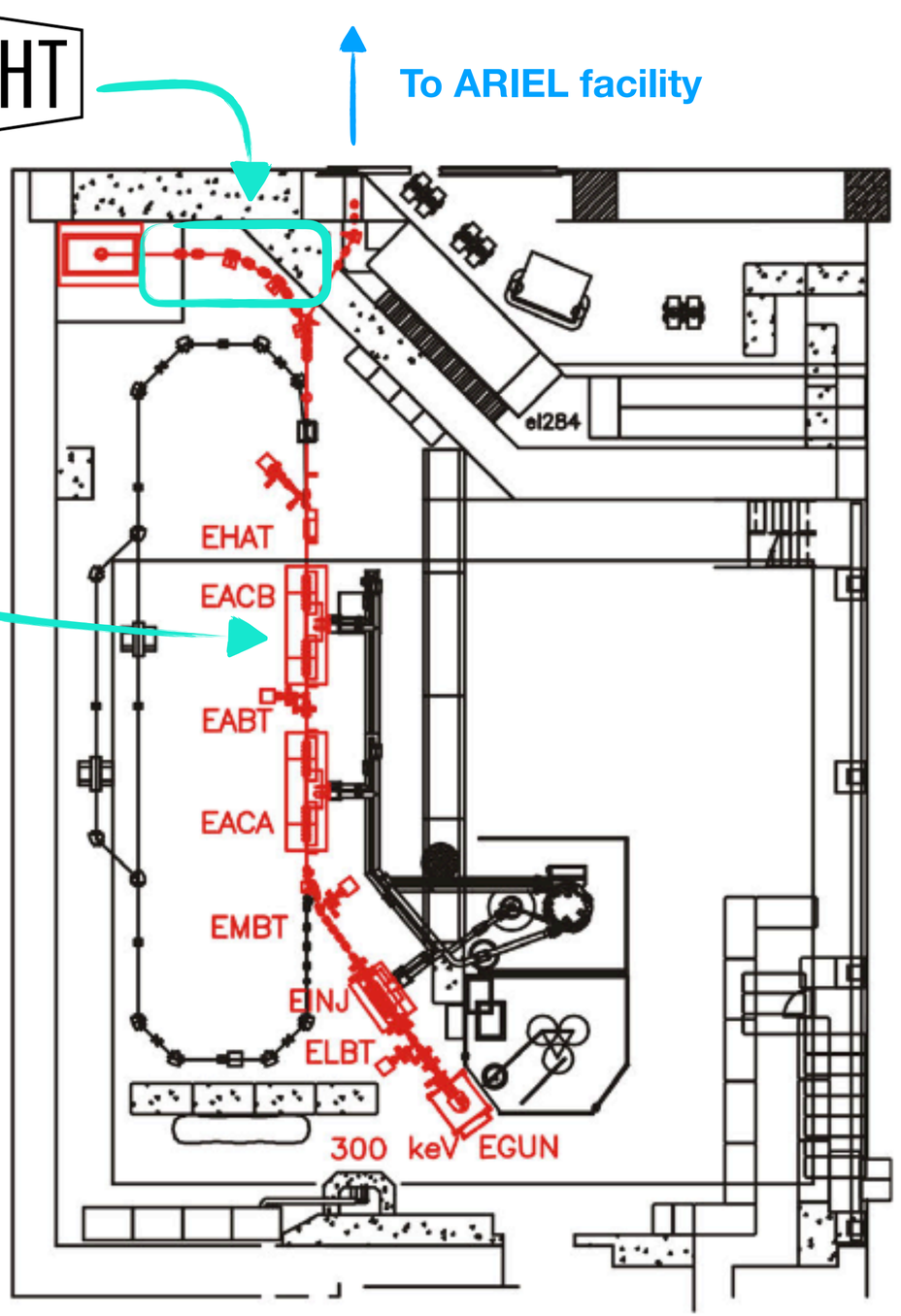
- 30 MeV electron beam setup
  - Best sensitivity is below 17 MeV
  - Excellent for commissioning



ARIEL eLinac

- 30 MeV electron beam setup
  - Best sensitivity is below 17 MeV
  - Excellent for commissioning

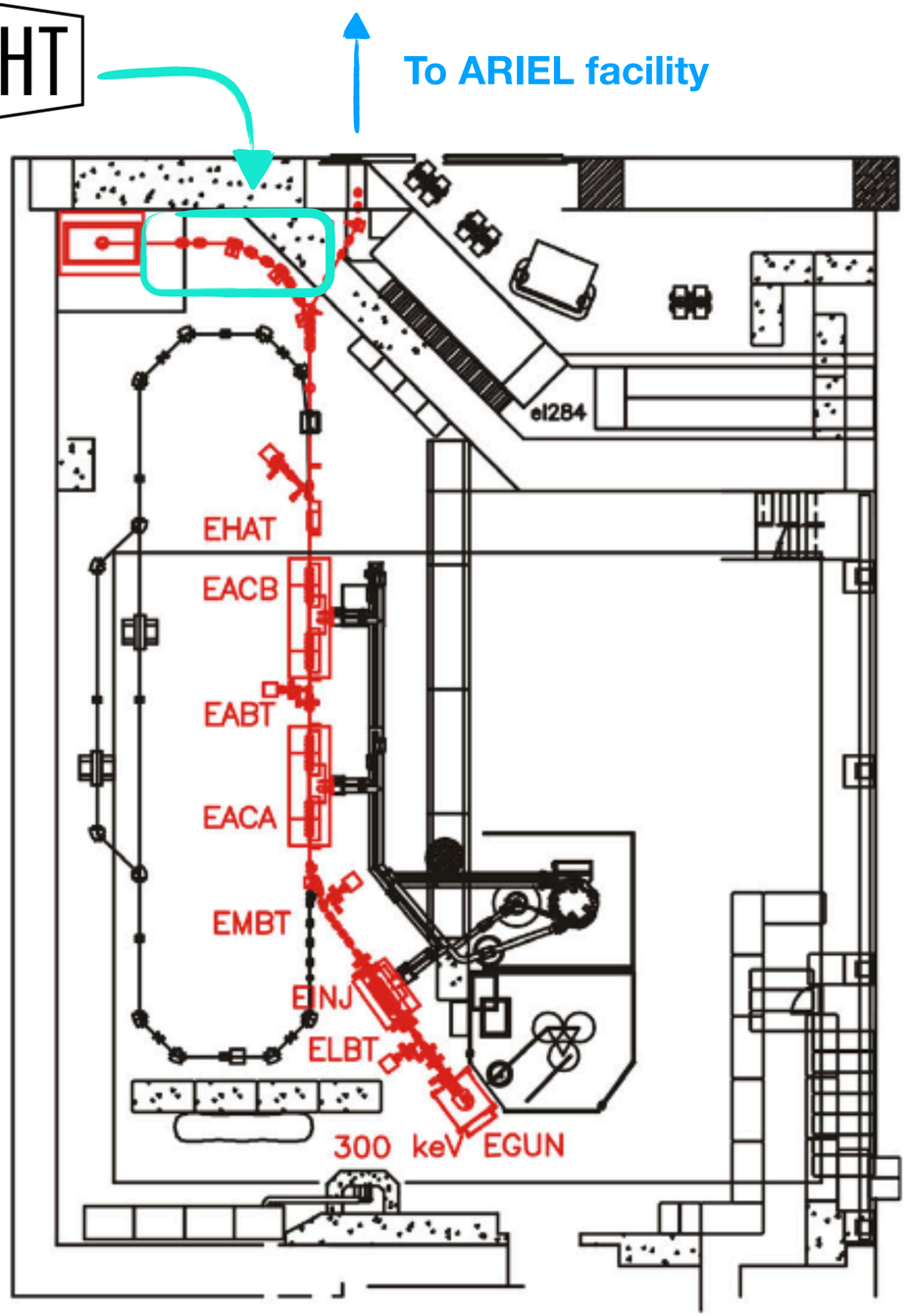
- 50 MeV upgrade: new cryomodule
  - Allows probe of X17 favoured region



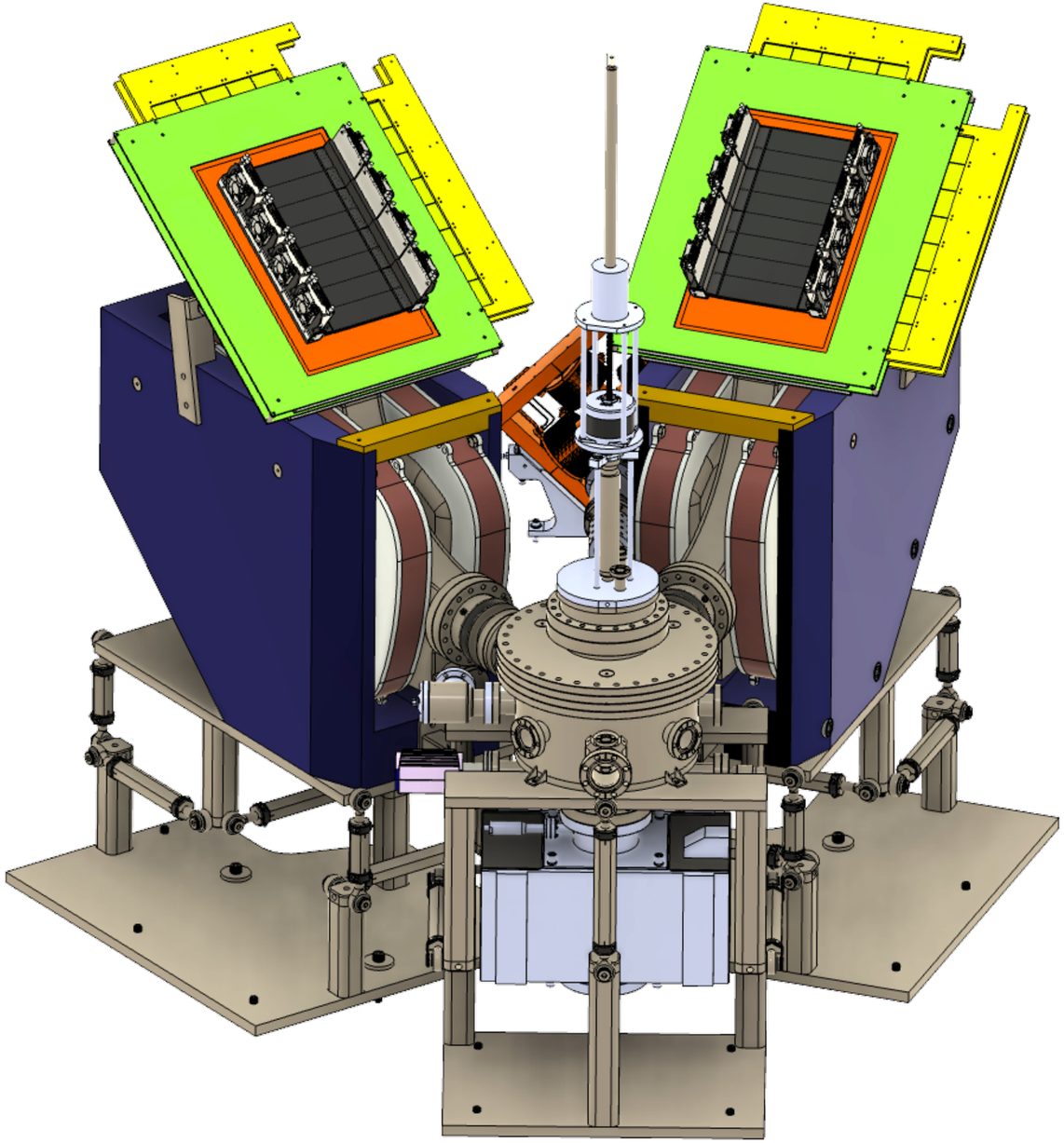
ARIEL eLinac

DARKLIGHT

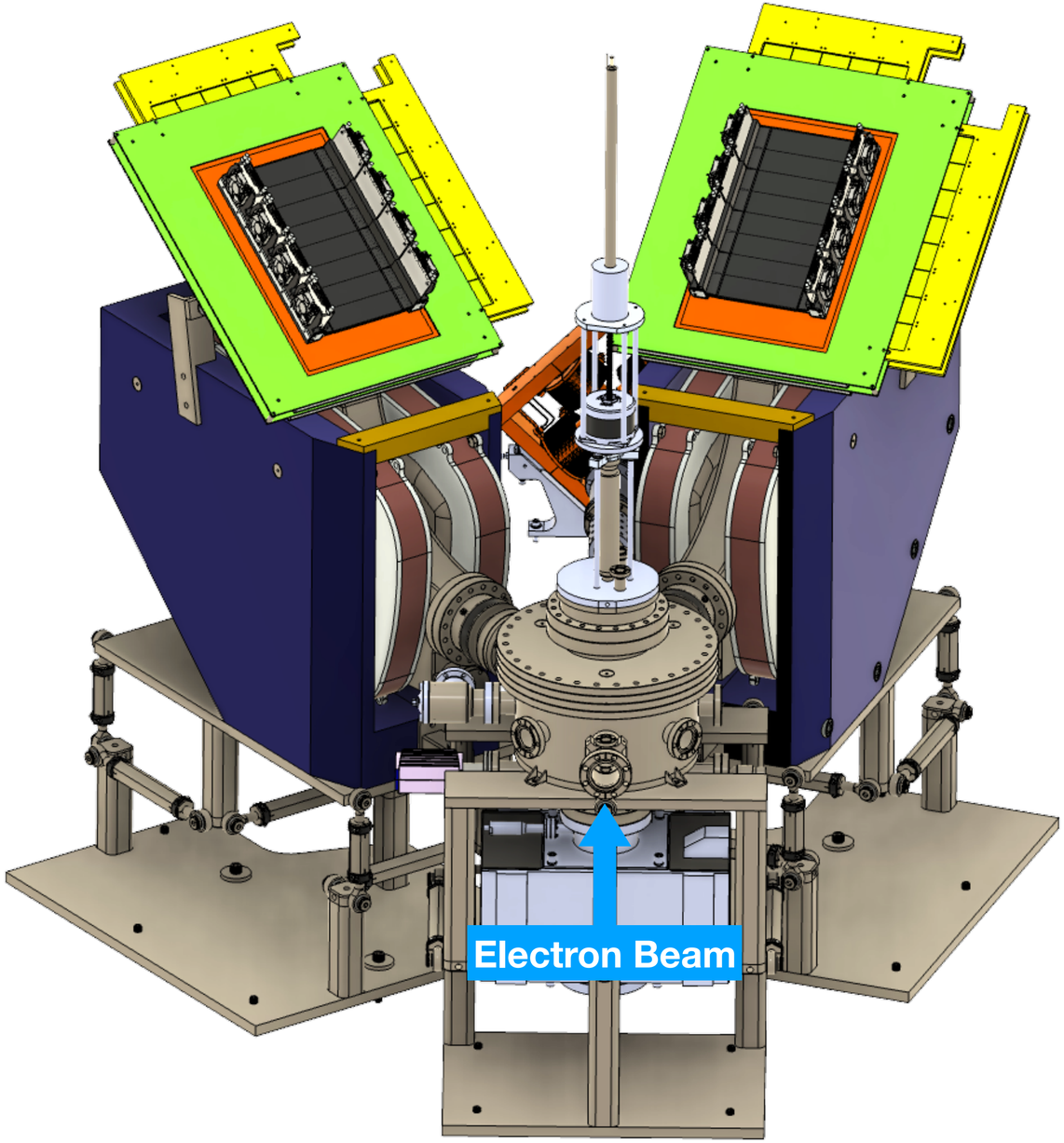
Pre May 2025



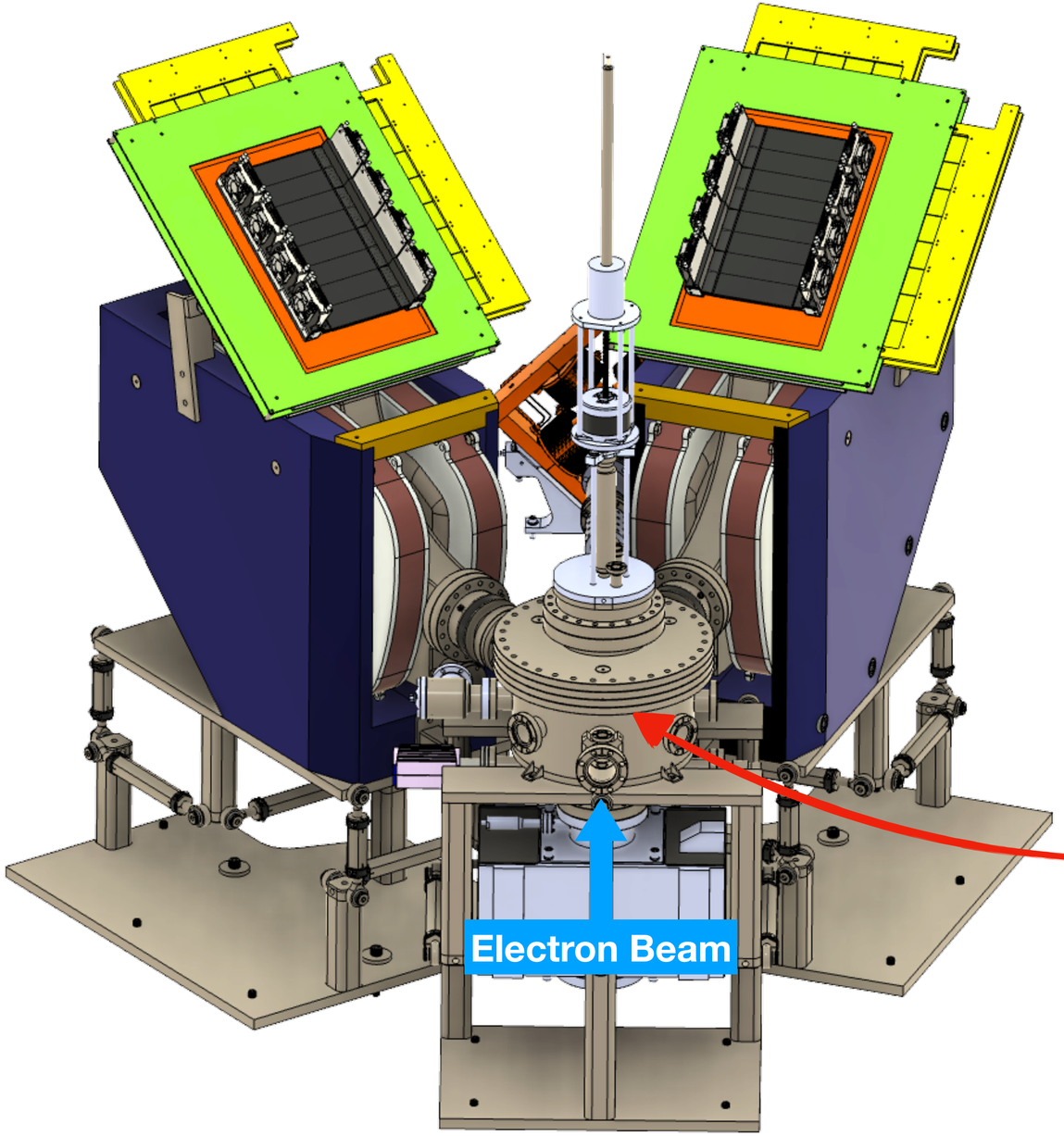
DarkLight Apparatus



DarkLight Apparatus

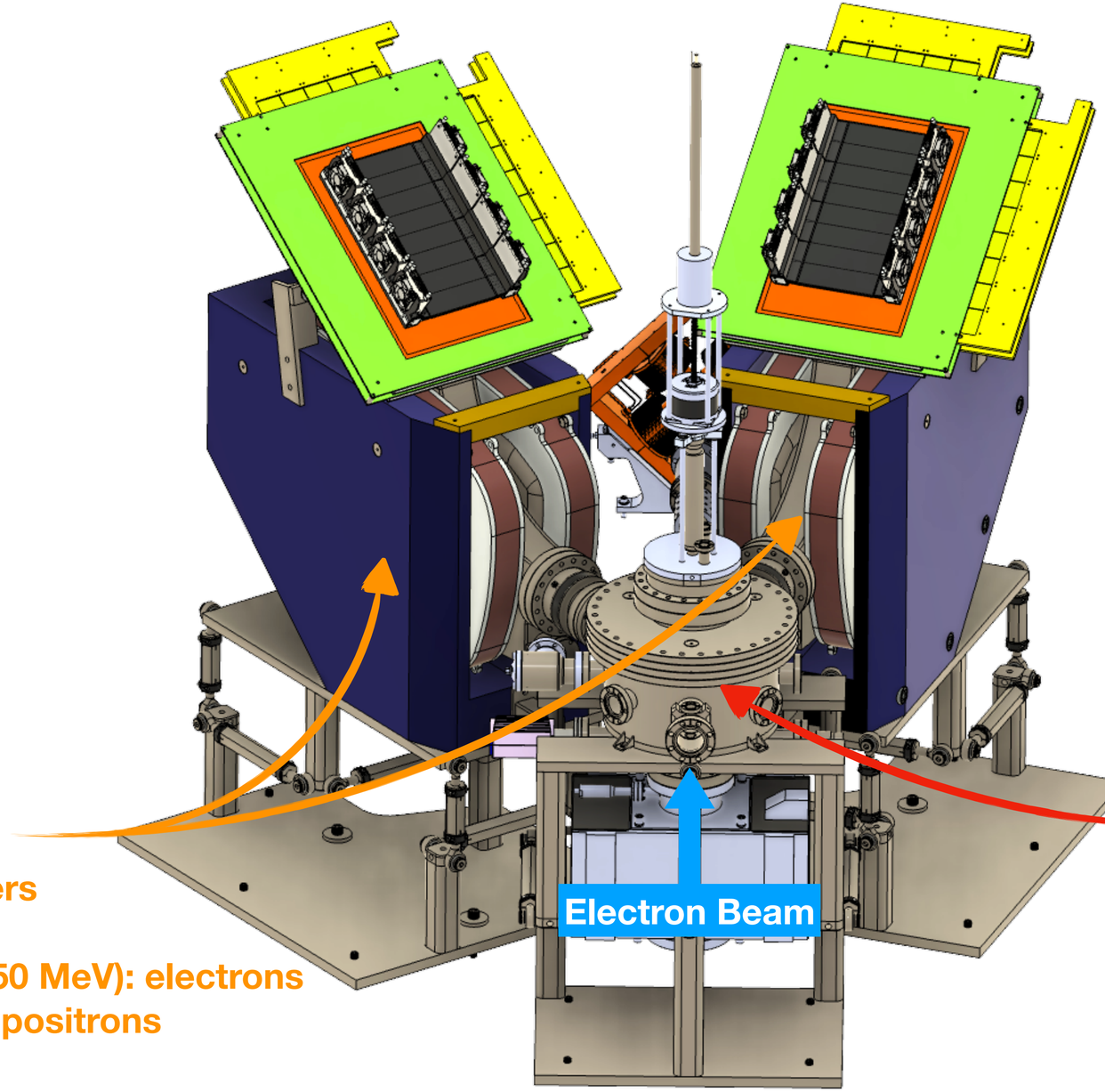


DarkLight Apparatus



Target chamber with
1 μm Tantalum target
or 1 μm Carbon target

DarkLight Apparatus

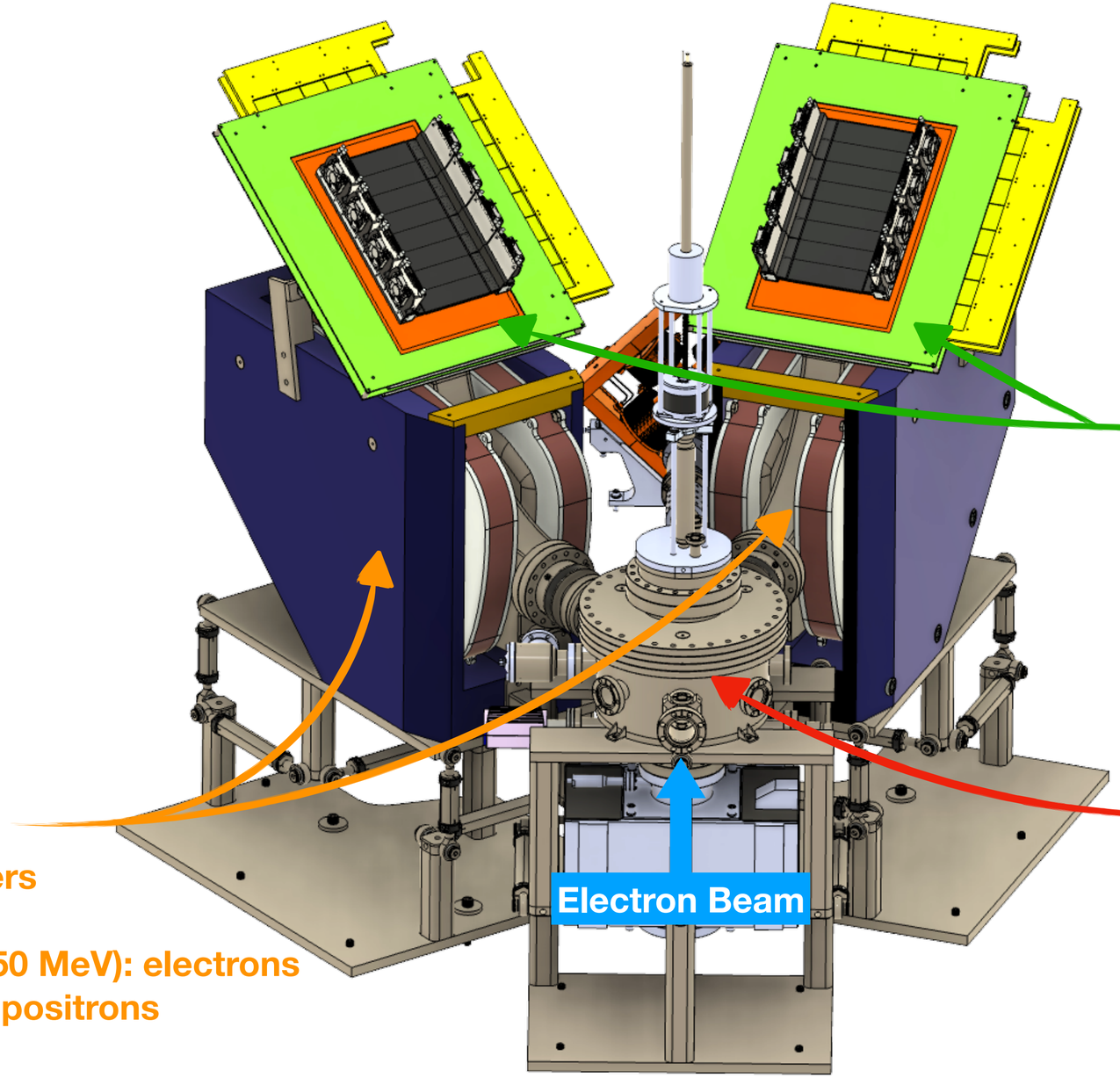


Target chamber with
1 μm Tantalum target
or 1 μm Carbon target

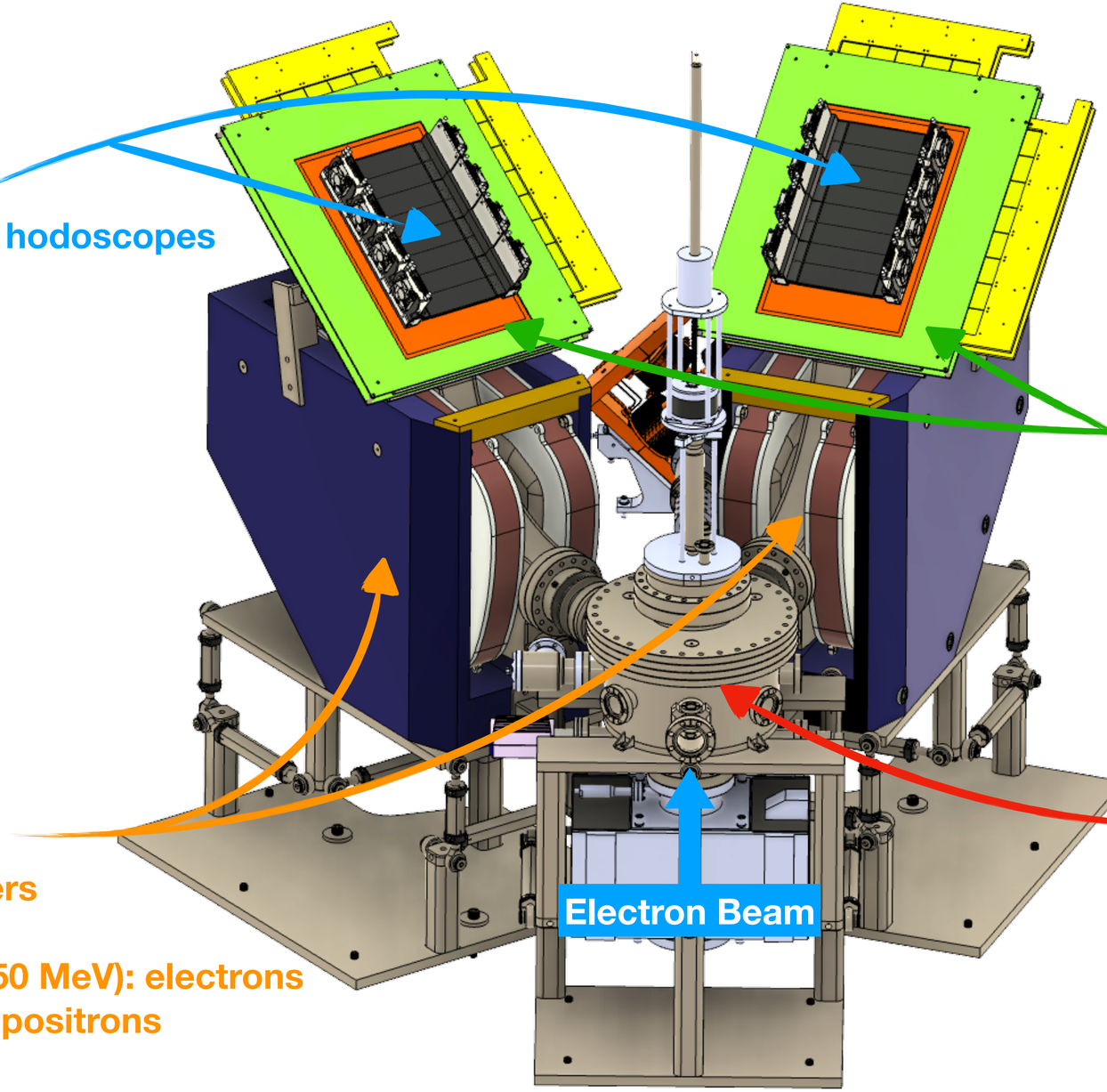
Spectrometers

Left (36° for 30 MeV, 20° for 50 MeV): electrons
Right (20° for both): positrons

DarkLight Apparatus



DarkLight Apparatus

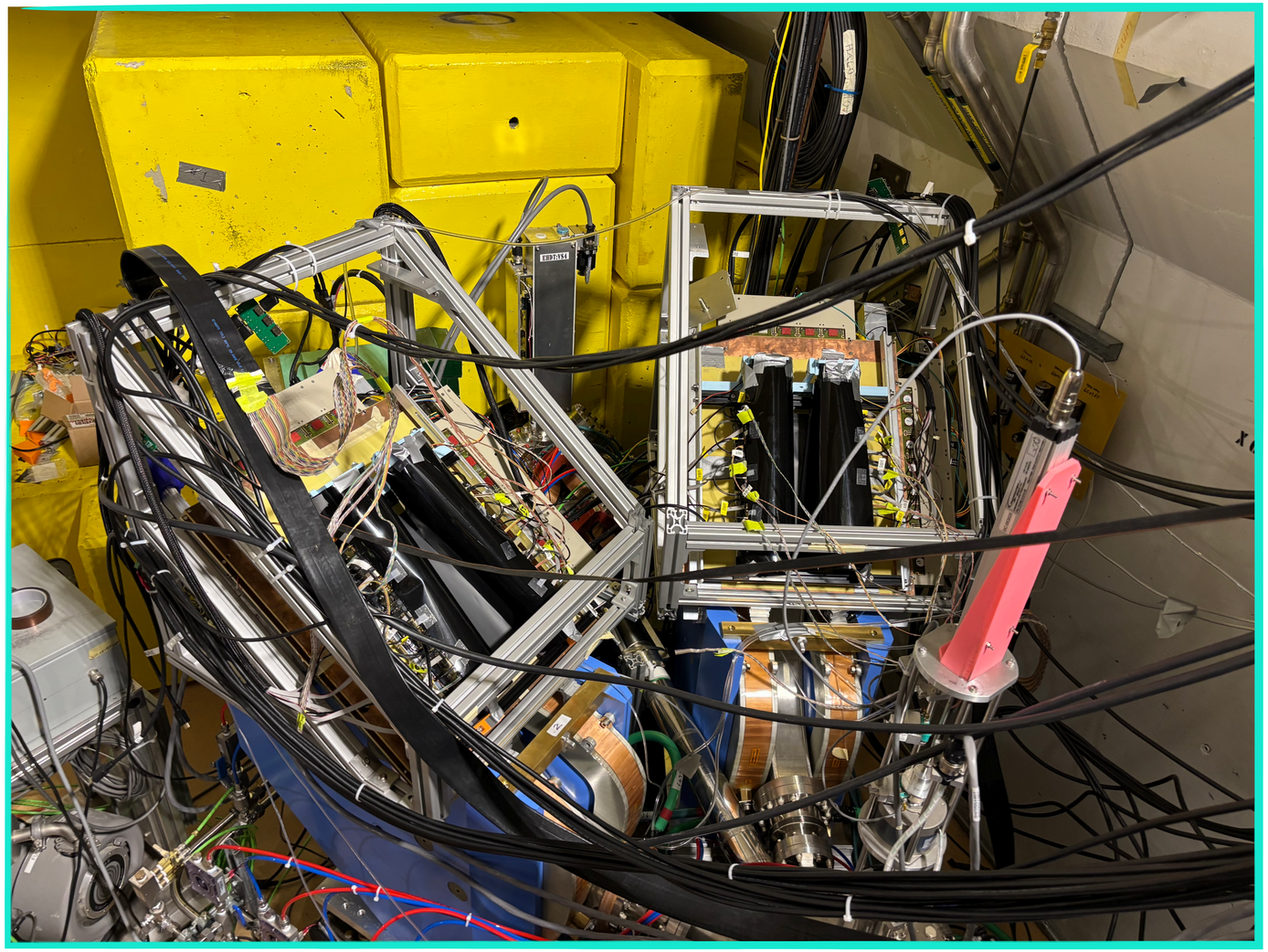


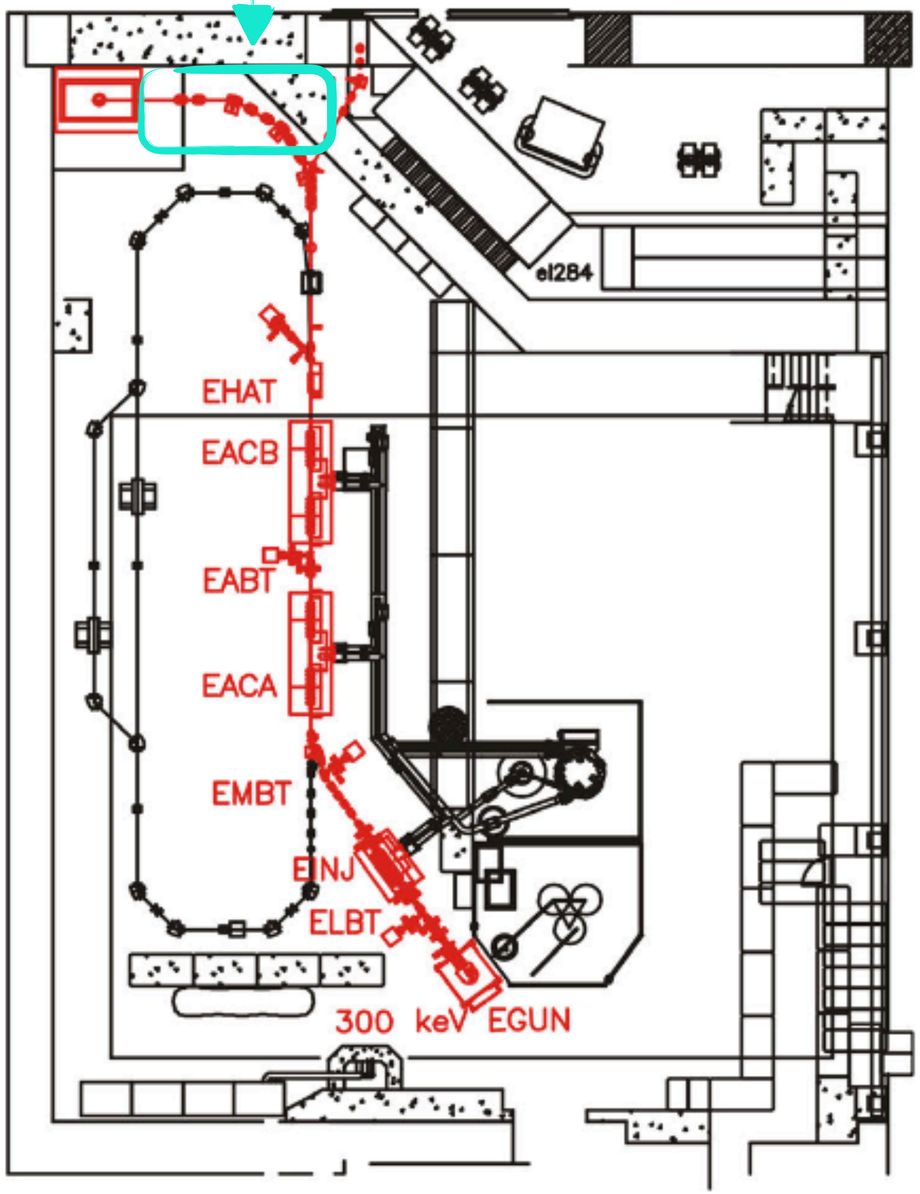
ARIEL eLinac

DARKLIGHT

To ARIEL facility

Post July 2025



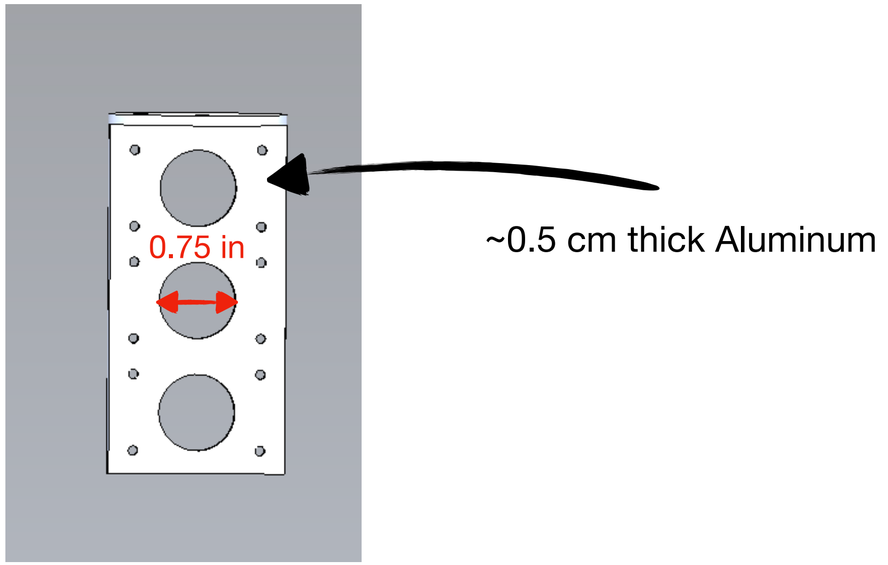


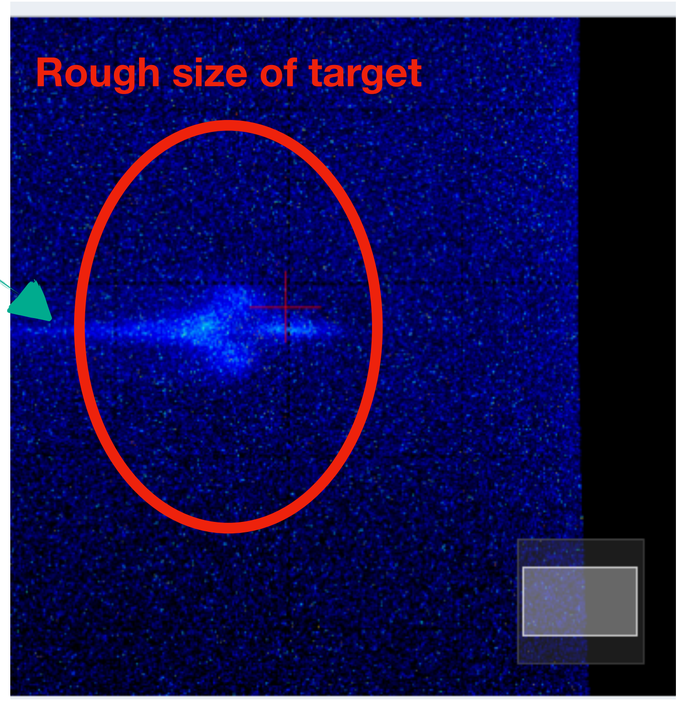
Commissioning: Early 2026

Goals	Success?
Ensure data acquisition system and detectors are functioning according to expectation	
Measure the carbon elastic scattering peak and radiative tail	
Measure inelastic carbon scattering	
Measure radiative Moller scattering	
Measure coincidences	

eLinac Commissioning

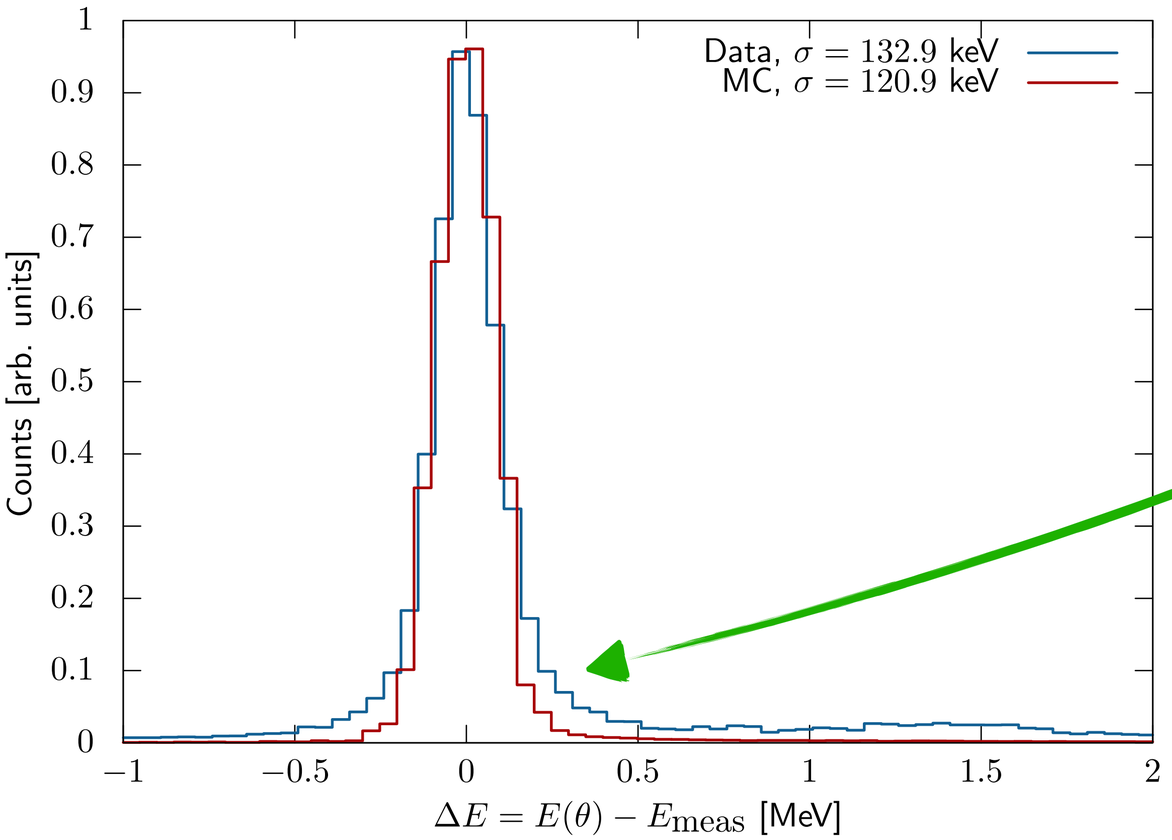
- The eLinac is a commissioning machine
- Beam is less well understood than expected
  - Dark current scattering through the target ladder frame
  - Larger than anticipated beam spot size

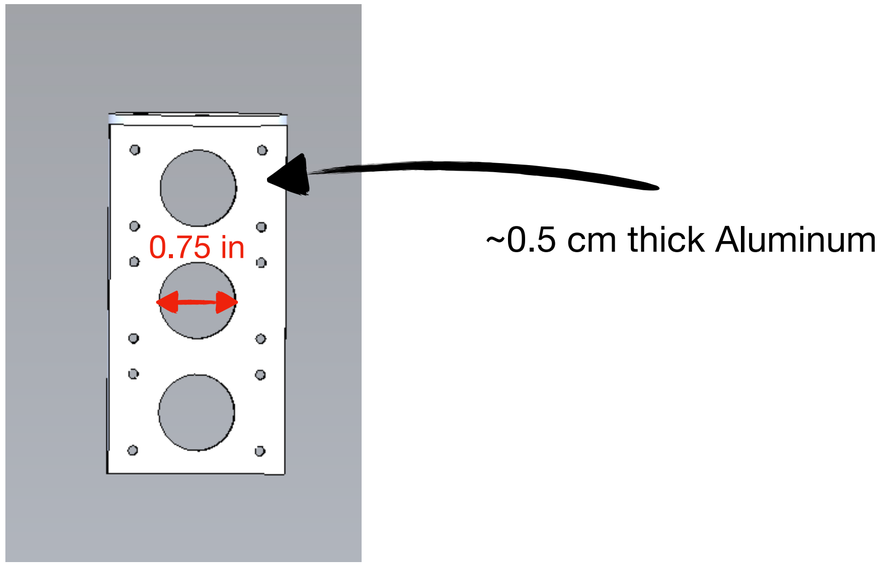


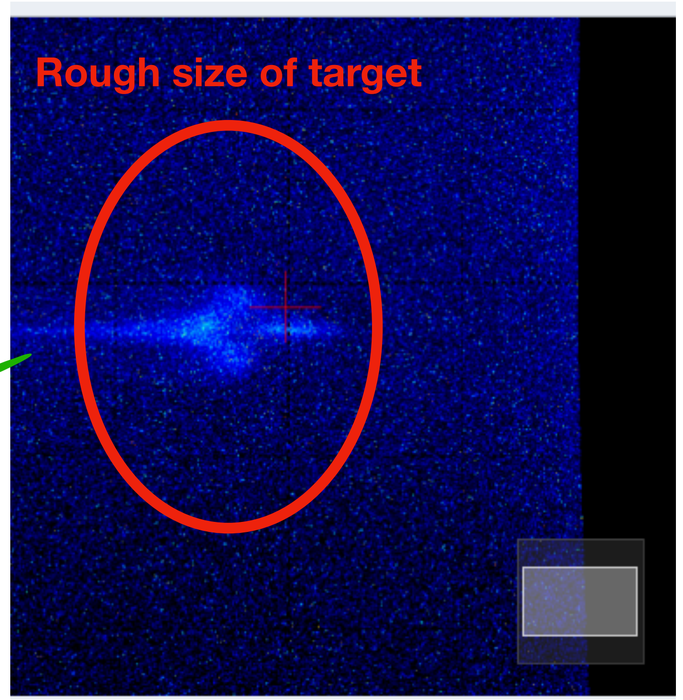


eLinac Commissioning

- The eLinac is a commissioning machine
- Beam is less well understood than expected
  - Dark current scattering through the target ladder frame
  - Larger than anticipated beam spot size

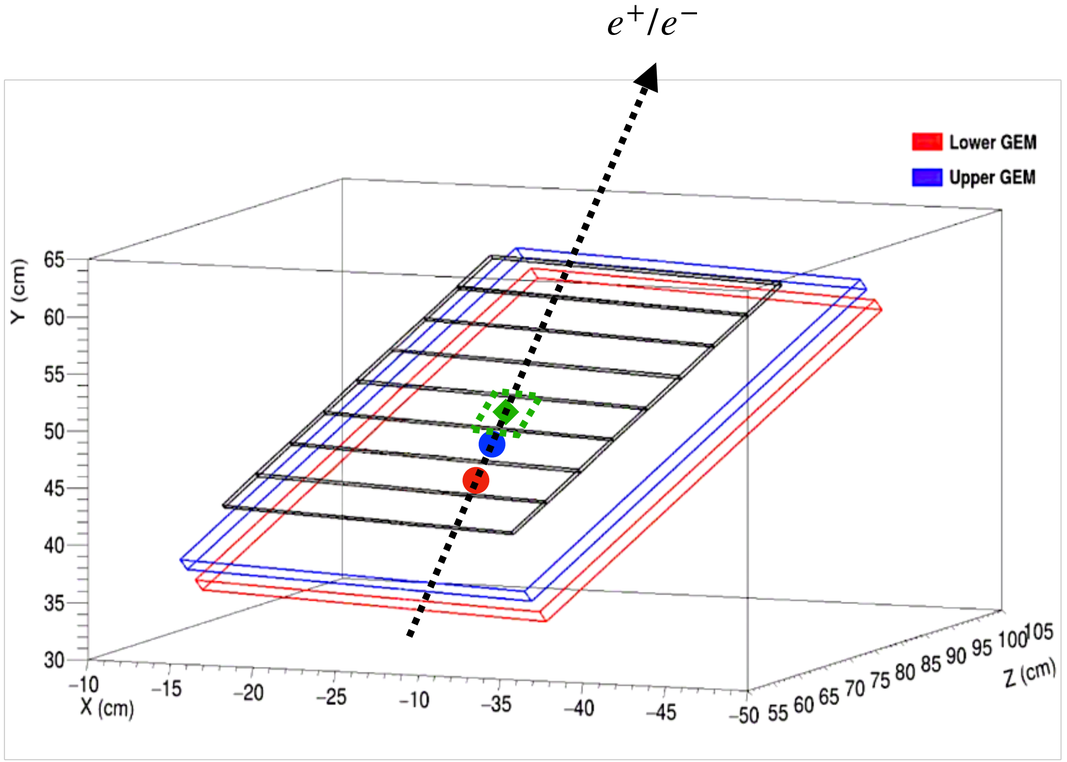






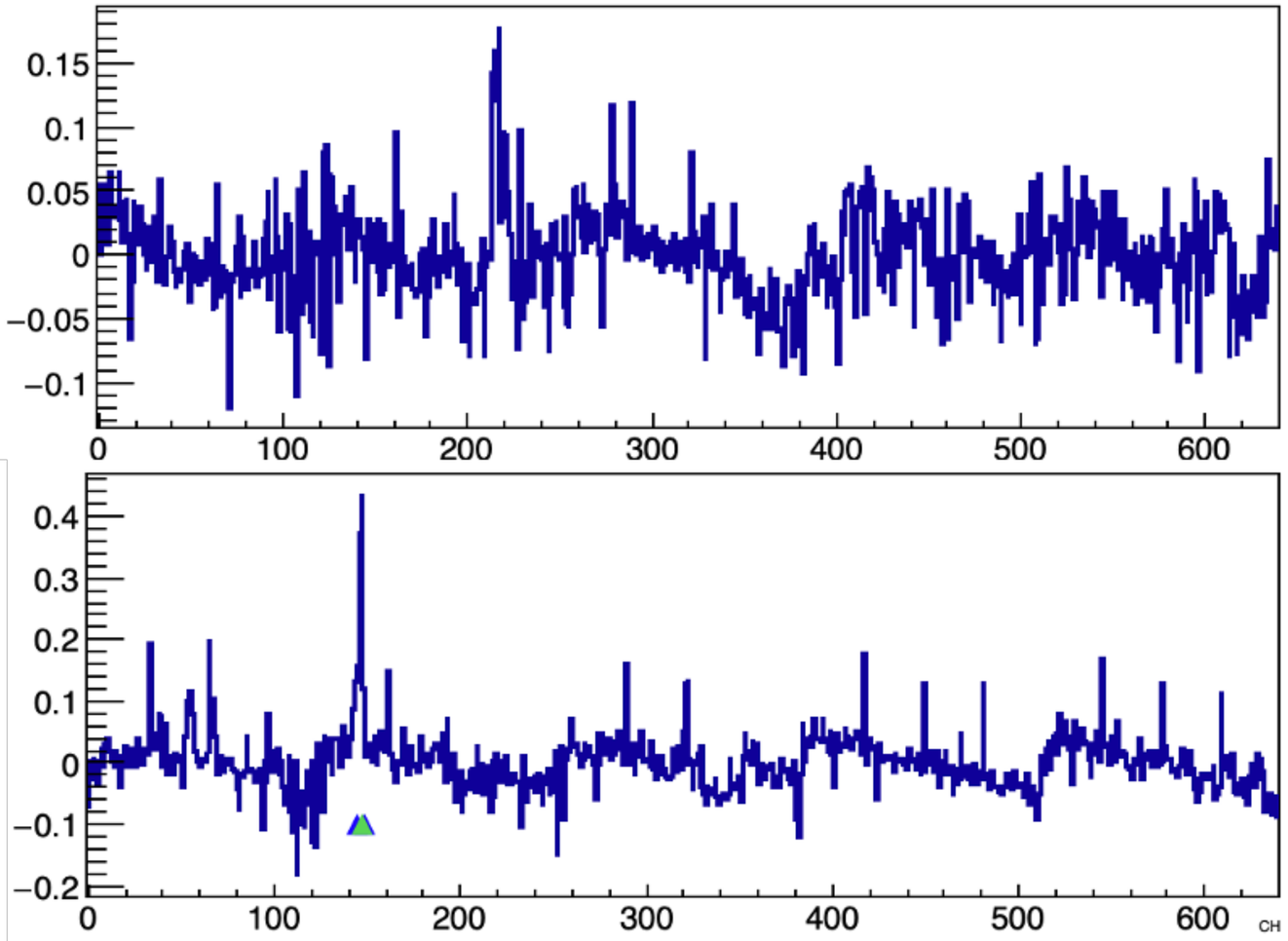
Detector Commissioning

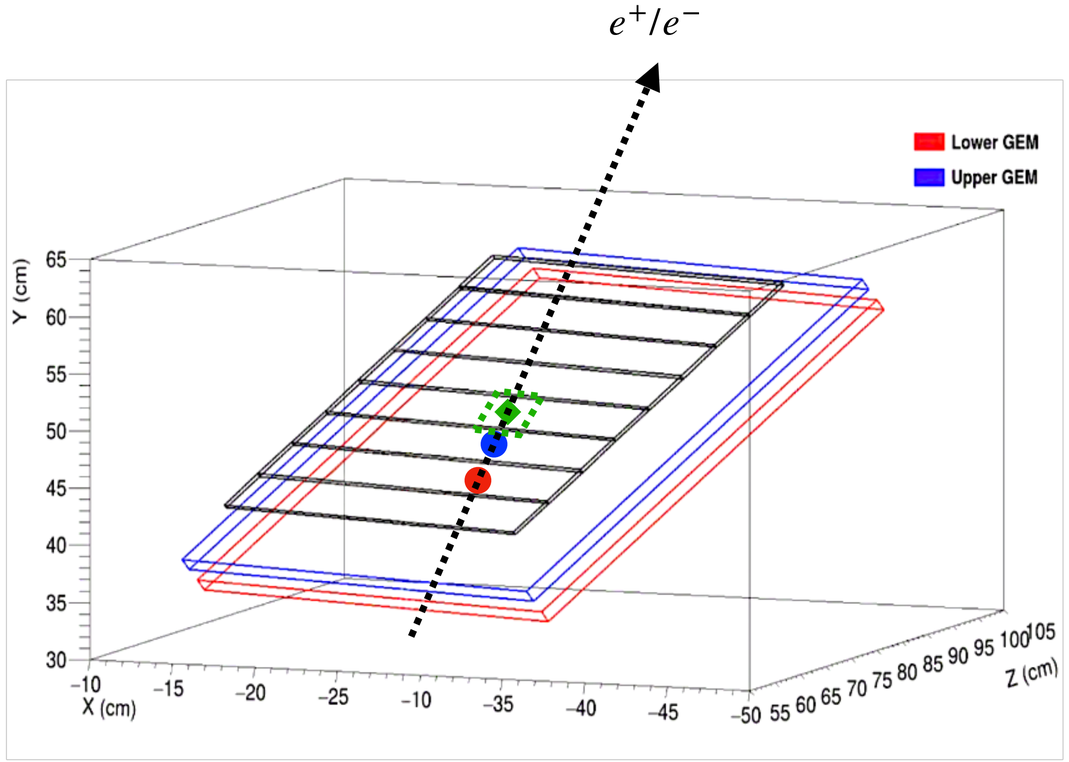
- GEMs are performing sub-optimally



Detector Commissioning

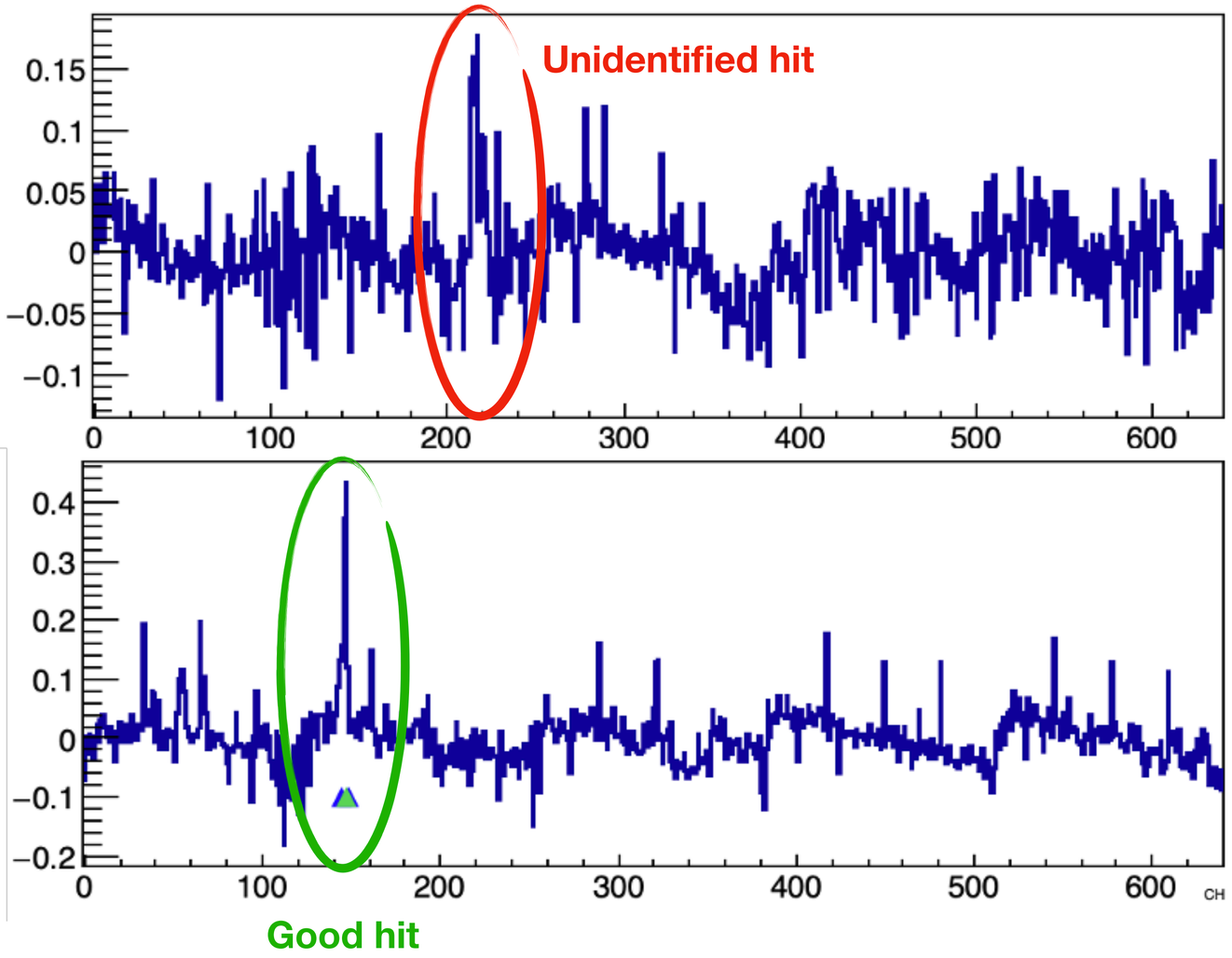
- GEMs are performing sub-optimally

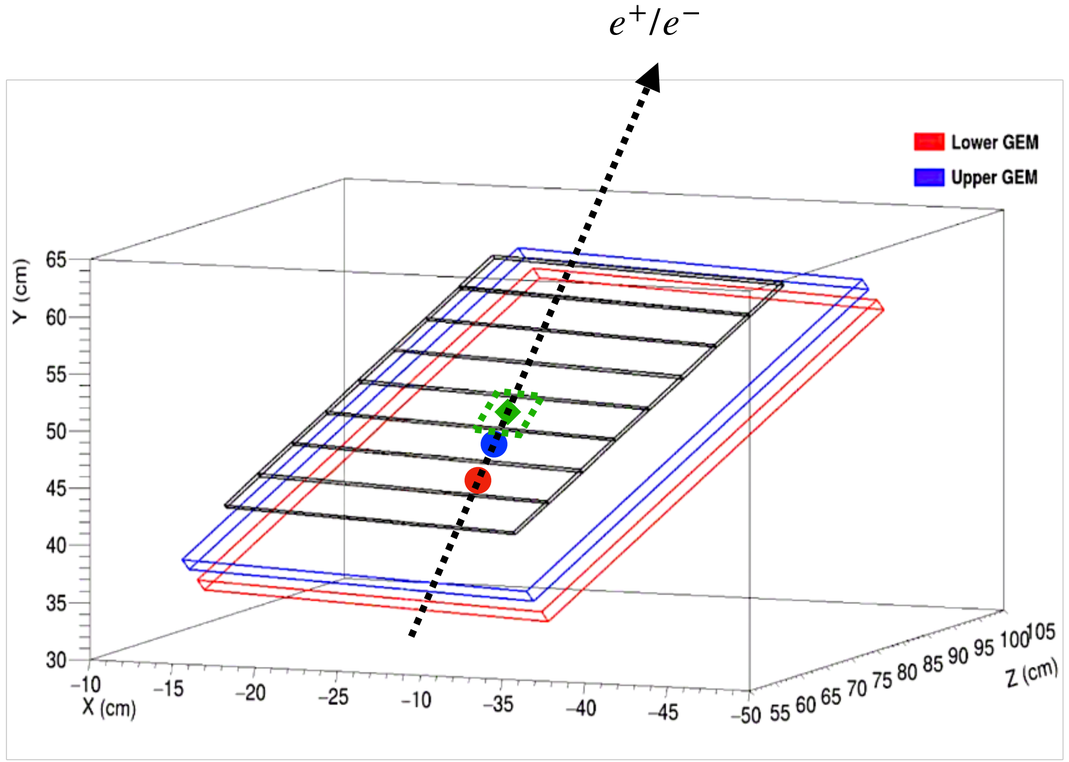




Detector Commissioning

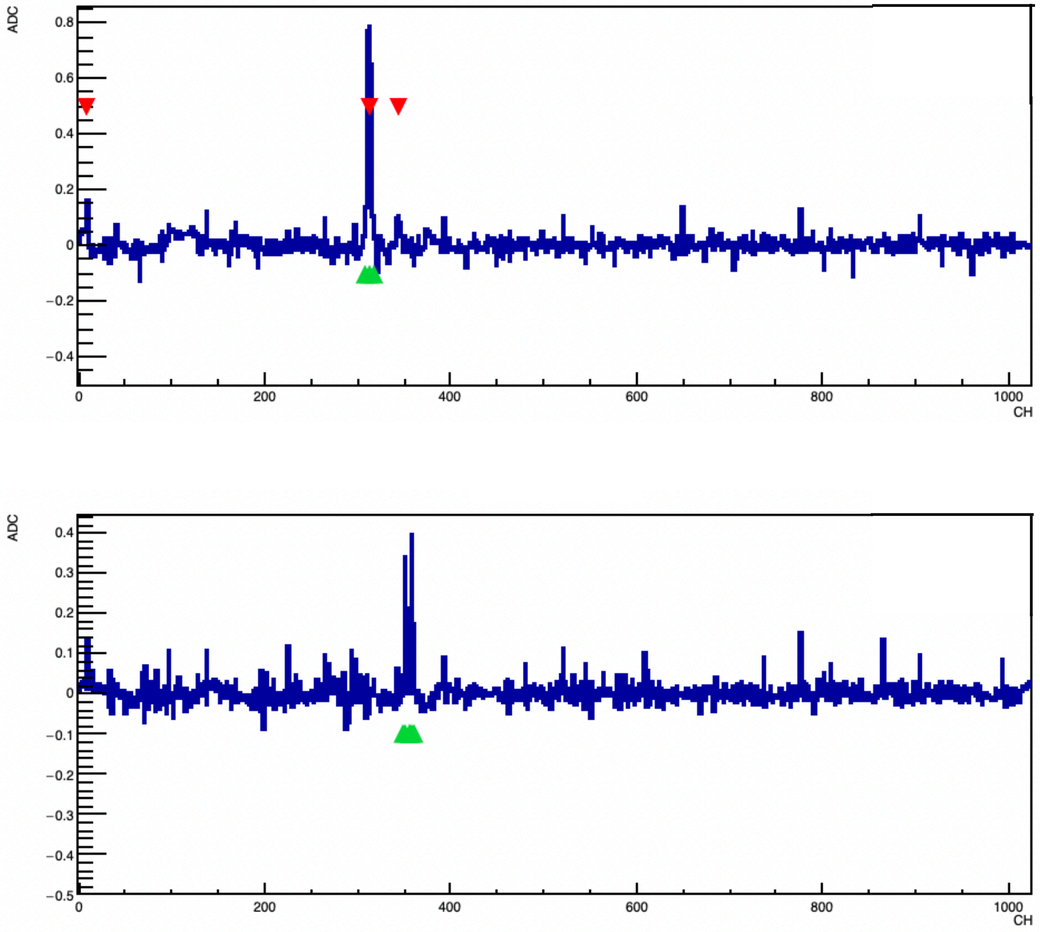
- GEMs are performing sub-optimally

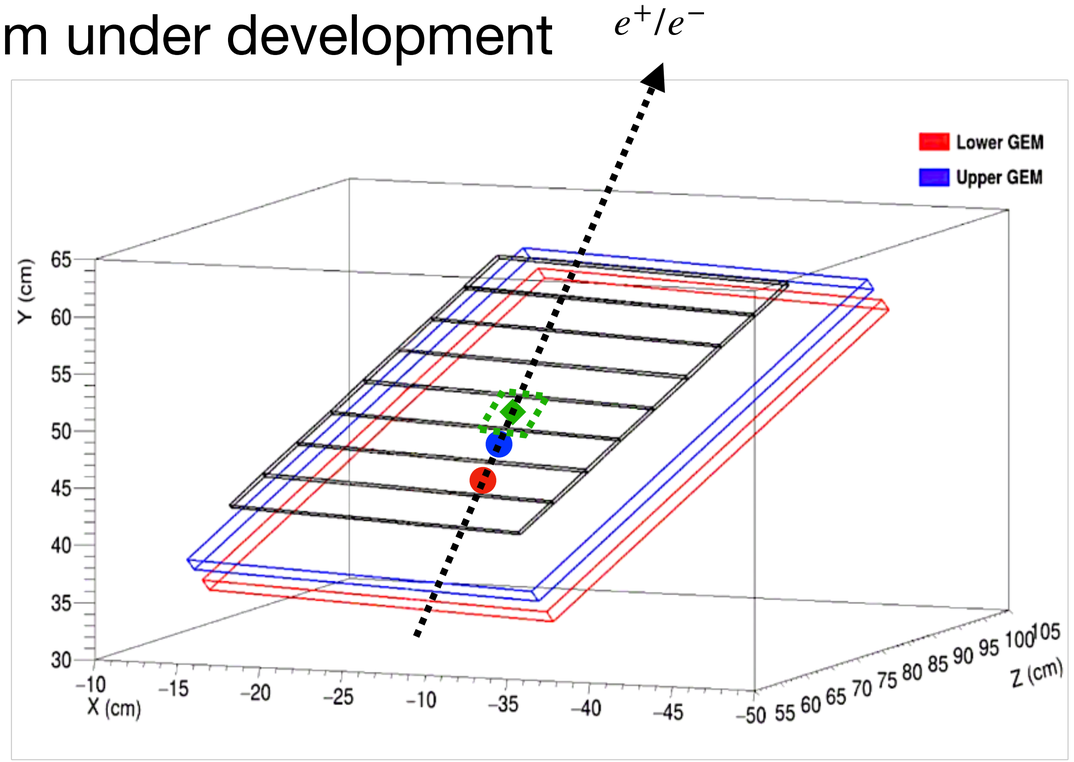




Detector Commissioning

- GEMs are performing sub-optimally
- Improved noise subtraction and clustering algorithm under development

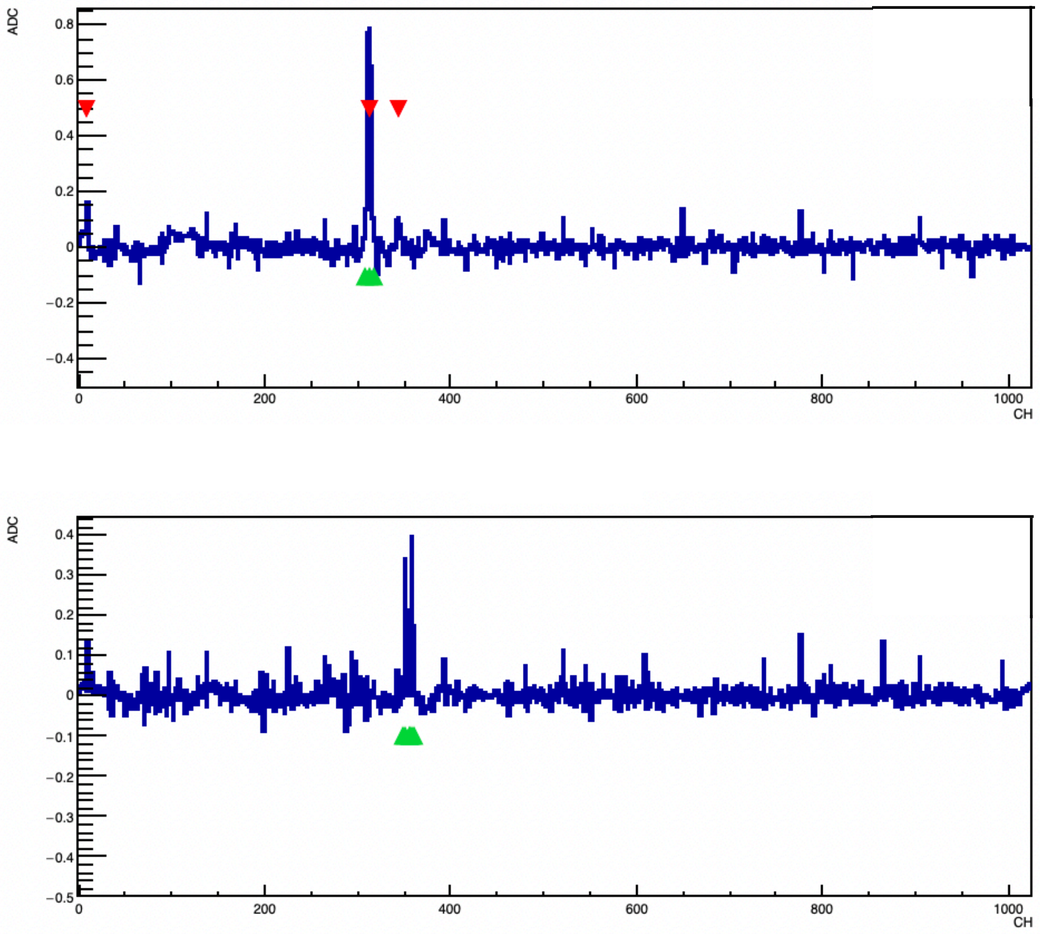


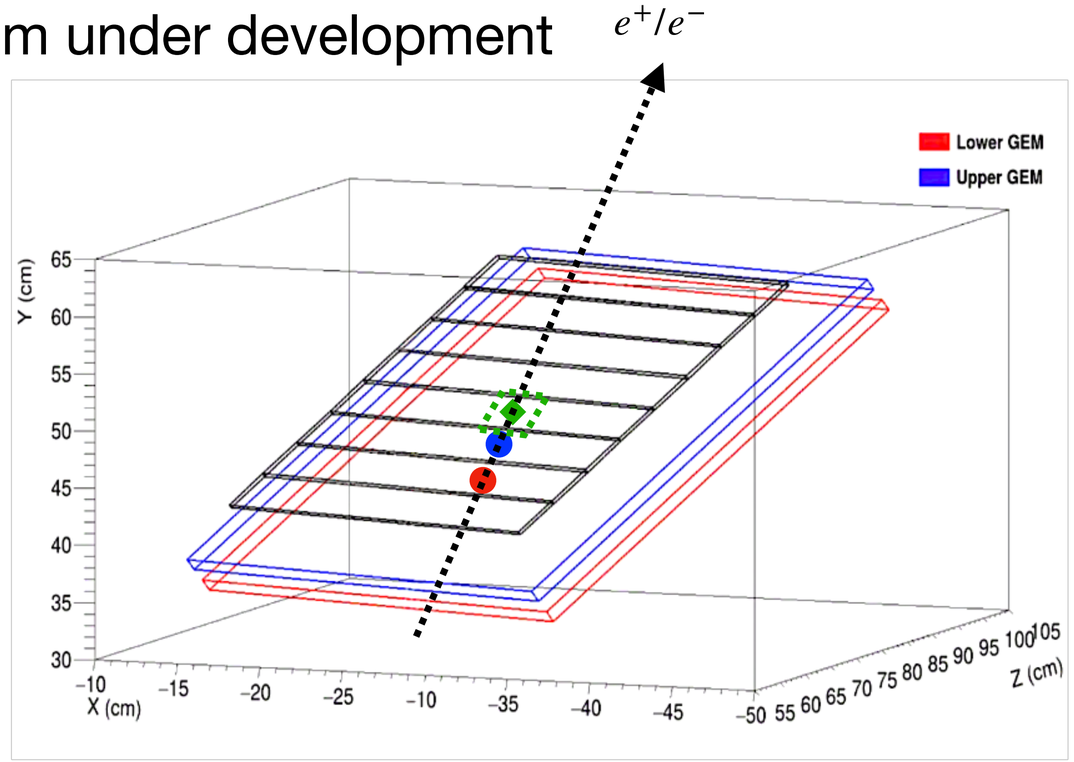


E. Fielding, D. Reiter

Detector Commissioning

- GEMs are performing sub-optimally
- Improved noise subtraction and clustering algorithm under development



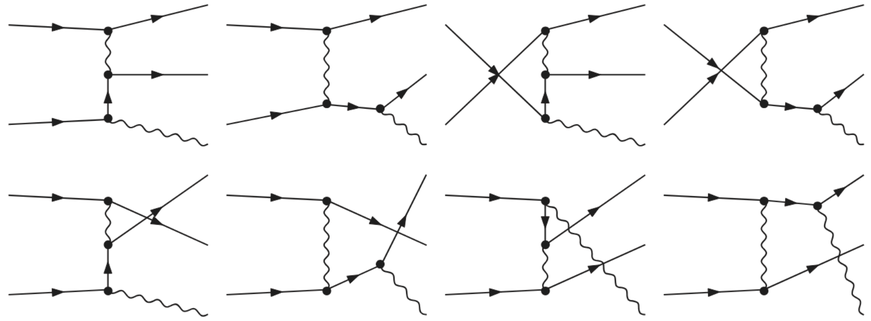


Exploring alternative detector technologies for future runs

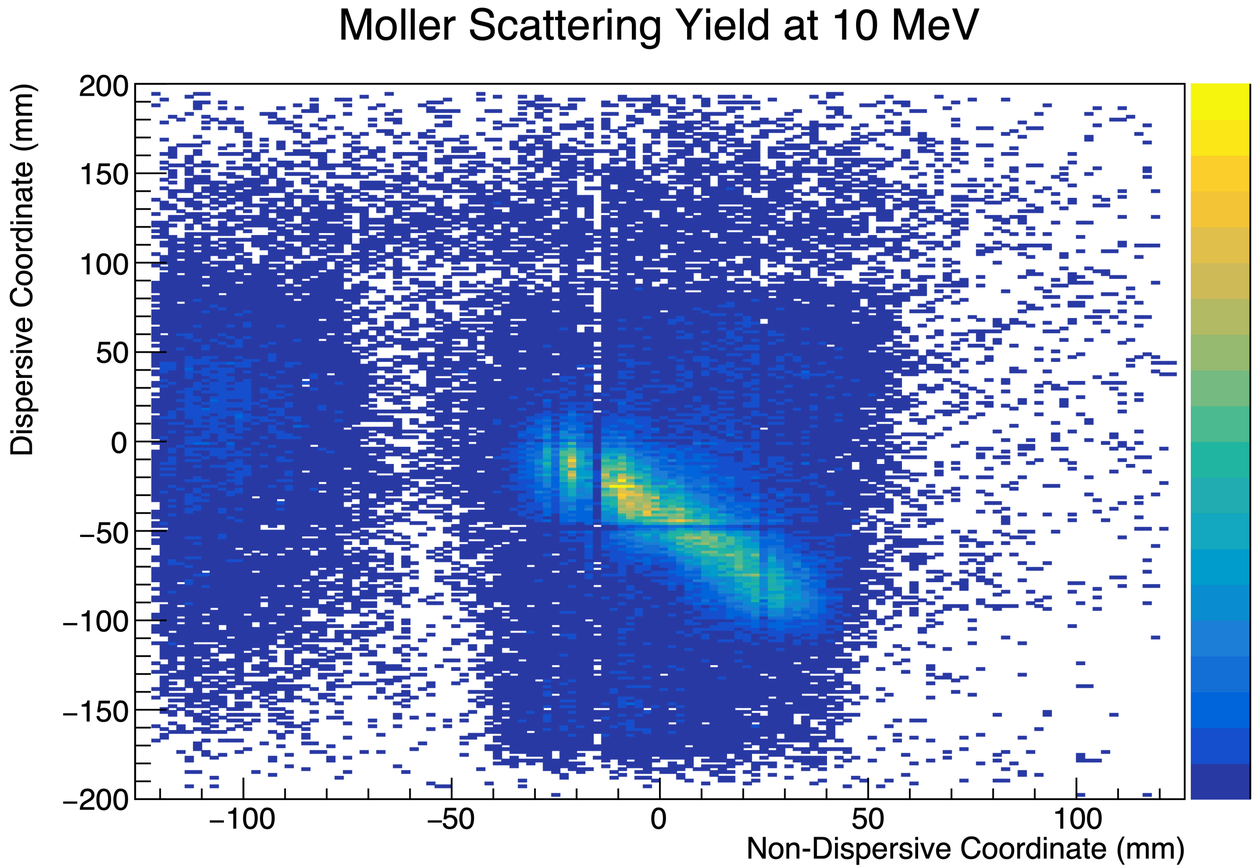
E. Fielding, D. Reiter

Commissioning Measurements

- Radiative Moller scattering
  - Generator cross check for energy ranges where the electron mass is non-negligible



PRD D 94, 033004 (2016)

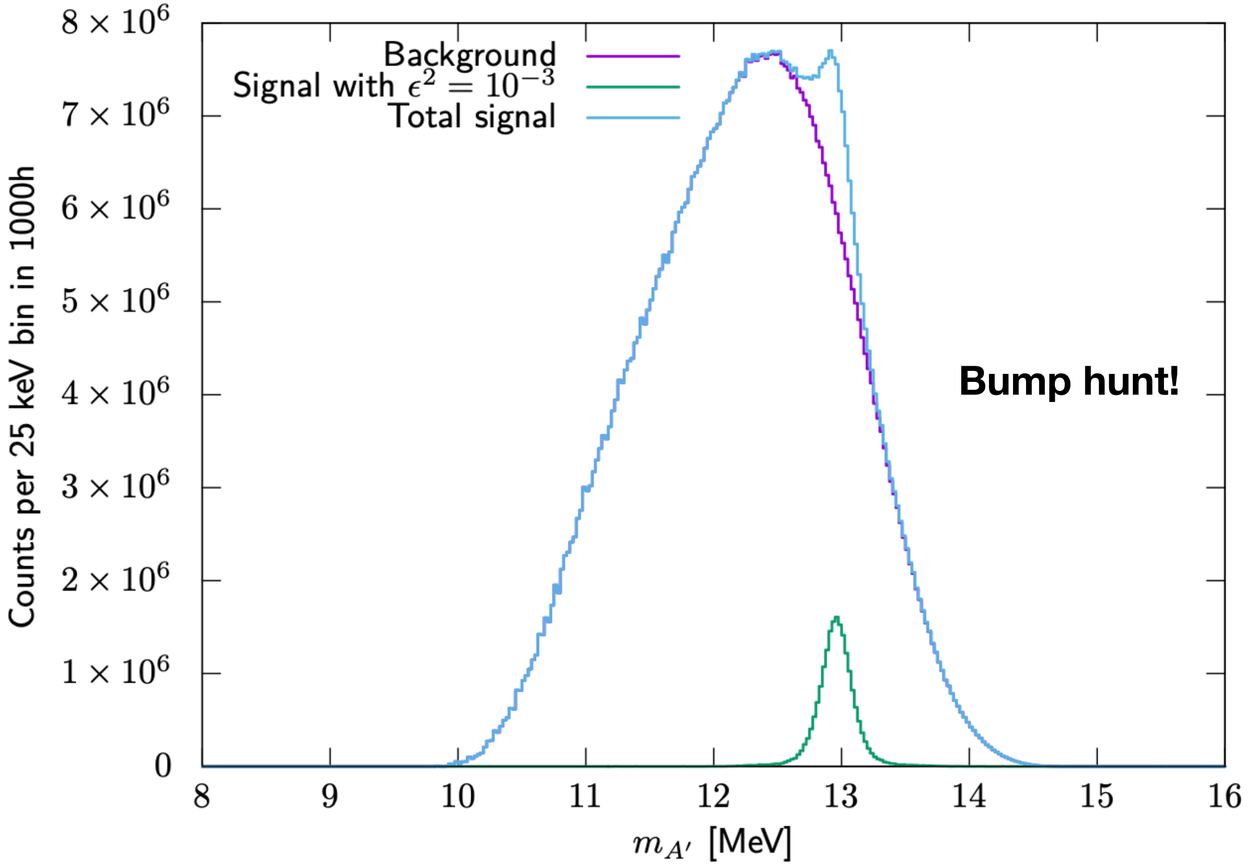


Commissioning: Early 2026

Goals	Success?
Ensure data acquisition system and detectors are functioning according to expectation	✅ (ish)
Measure the carbon elastic scattering peak and radiative tail	✅ (ish)
Measure inelastic carbon scattering	❌ (probably)
Measure radiative Moller scattering	✅
Measure coincidences	??

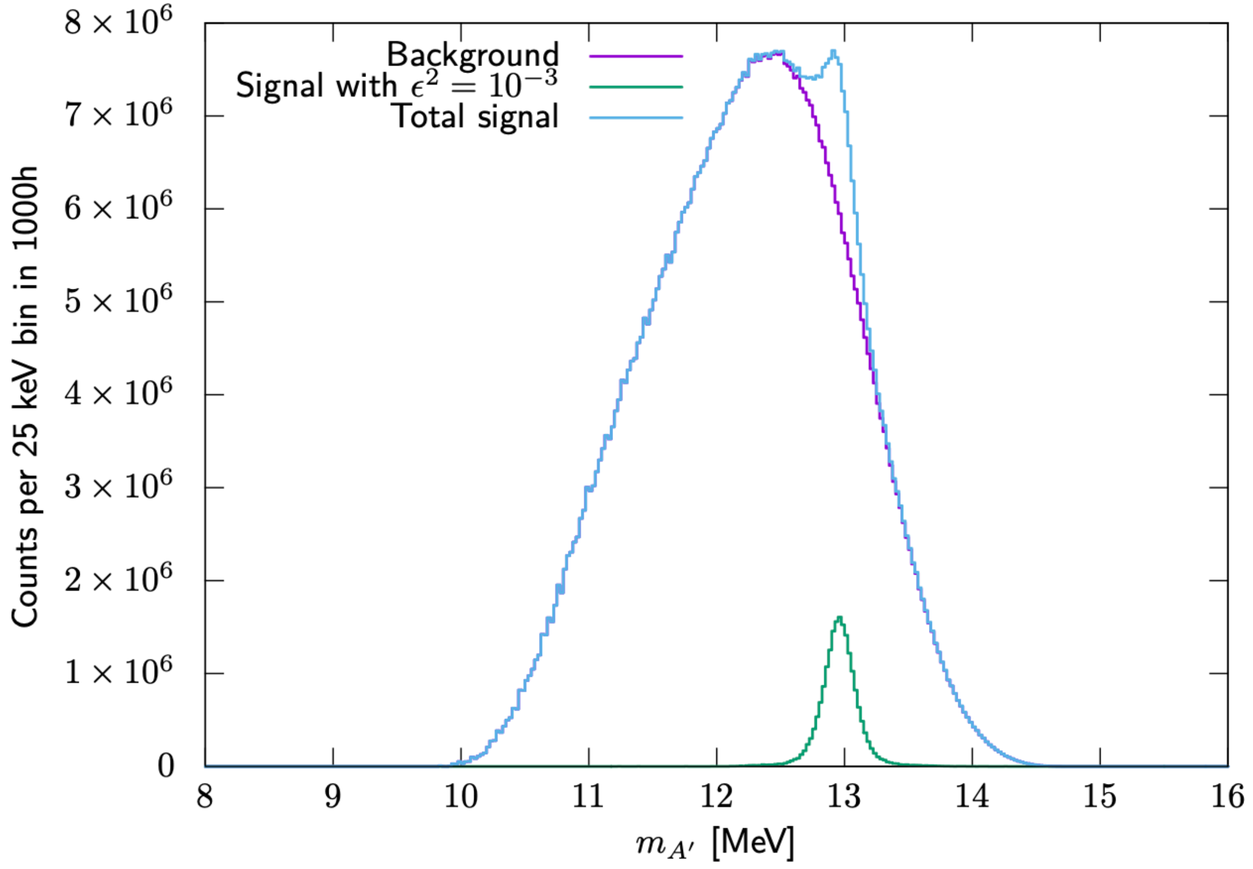
Upcoming Coincidence Measurements

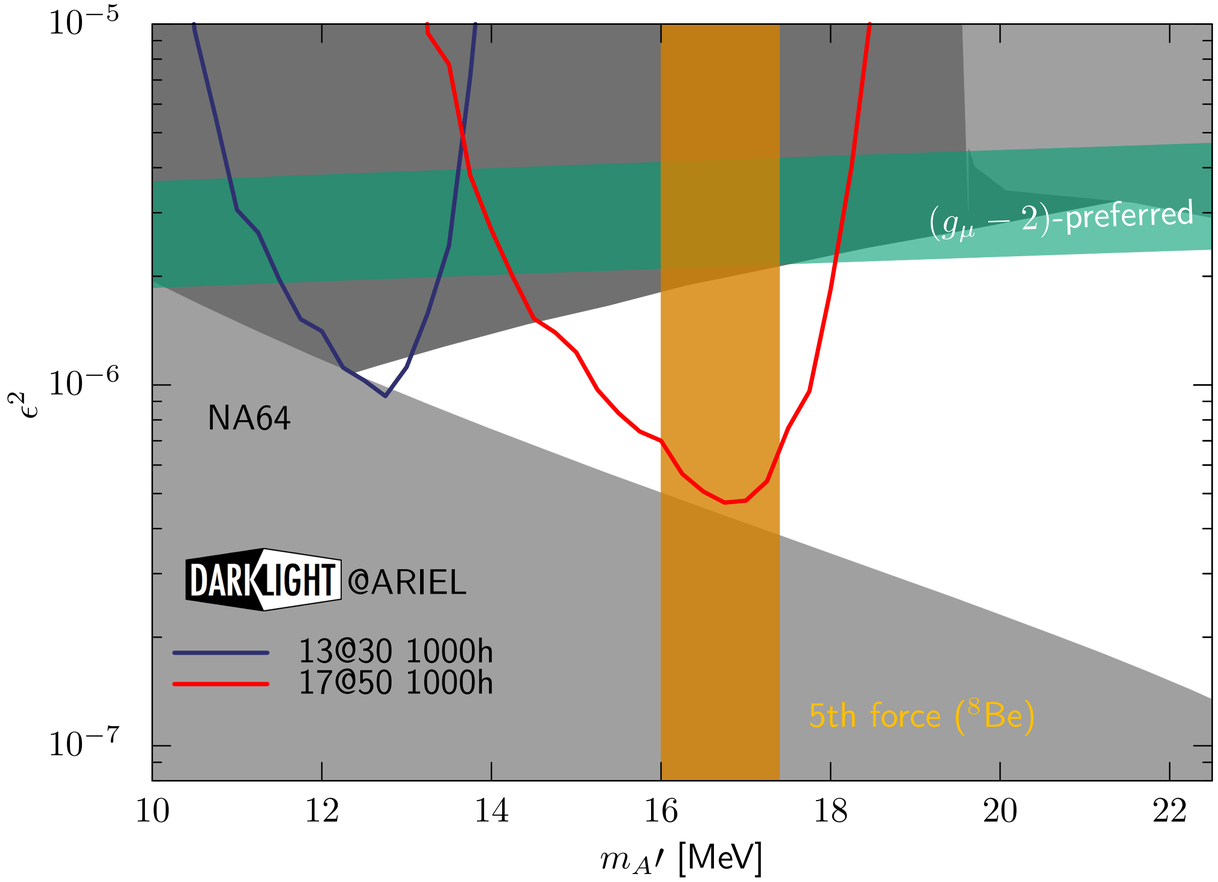
- Planning for additional runs with the eLinac beam at 30 MeV in 2027 (TRIUMF currently in long shutdown)
- Ongoing collaboration with JLAB to install a new cryomodule to upgrade energy to 50 MeV in 2028



Upcoming Coincidence Measurements

- Planning for additional runs with the eLinac beam at 30 MeV in 2027 (TRIUMF currently in long shutdown)
- Ongoing collaboration with JLAB to install a new cryomodule to upgrade energy to 50 MeV in 2028

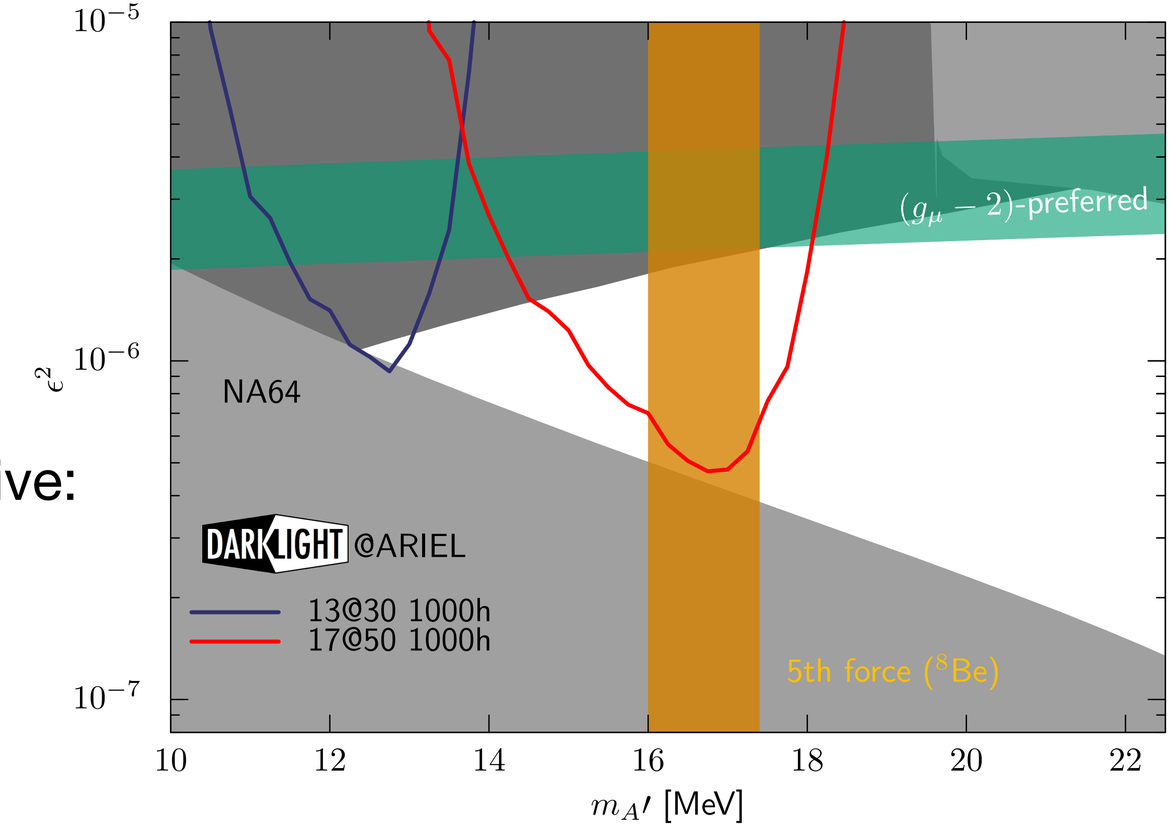




Open to Reinterpretation

- **DarkLight is a model-agnostic experiment**

- Assorted ideas:
  - Low hanging fruit/would benefit from increased acceptance, unclear if we are sensitive:
    - Different mediator interpretations
    - ALPs with electron coupling
    - QED mesons
  - Would require additional detectors
    - LLPs
    - ALPs with photon coupling
    - Inelastic electron-nucleon scattering to help constrain neutrino scattering models



Your favourite model that can be probed with our setup (or extensions of it)!

Email me

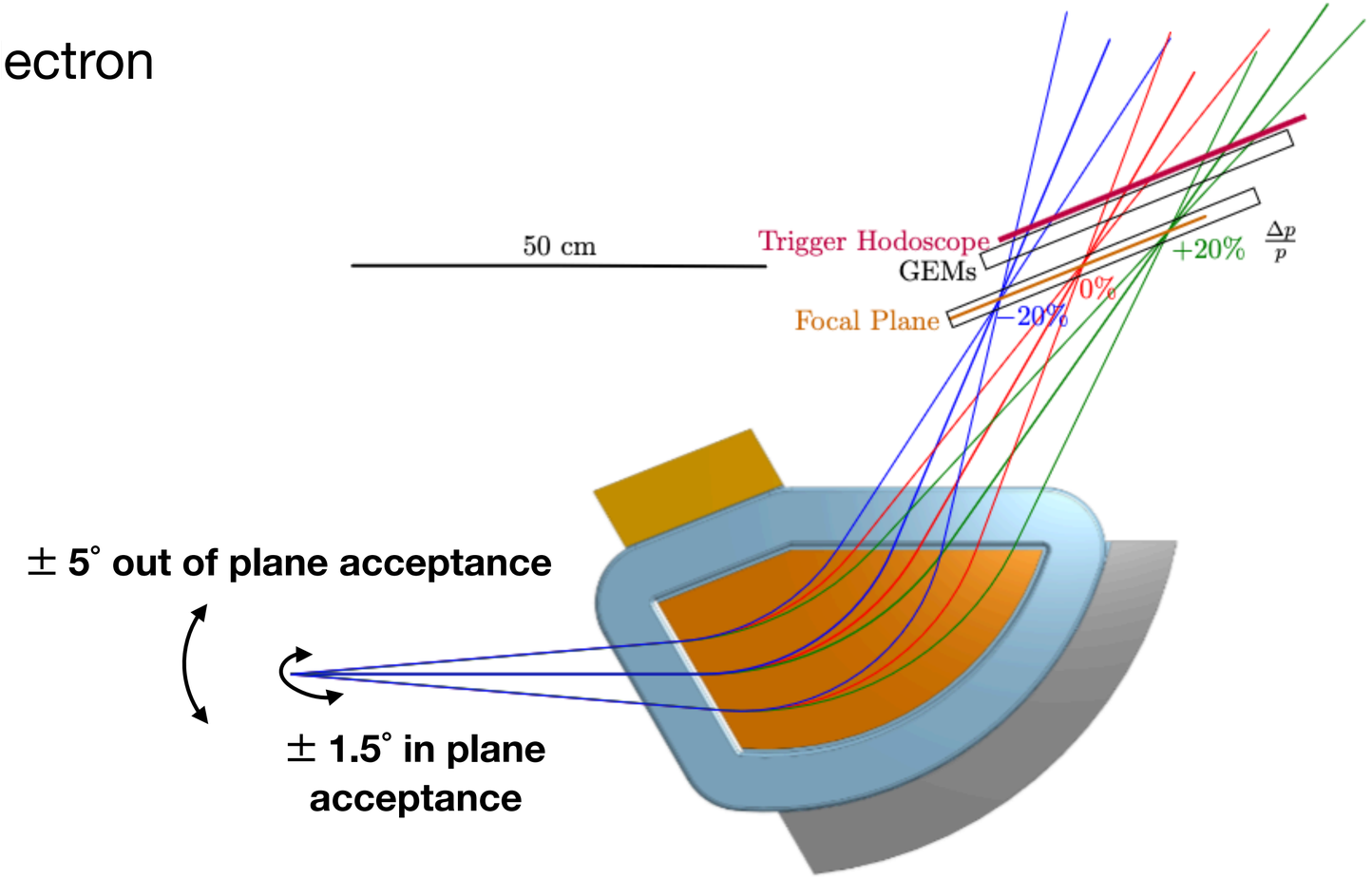
Thanks for listening! Questions?

Backup

Spectrometers

- Two dipole spectrometers (0.32 T, maximum 28 MeV central momentum)
- Arm angles set to 36° and 20° for the electron and positron arms, respectively
- Central momenta: 11.0 MeV for e^- arm and 17.2 MeV for e^+ arm

± 20% momentum acceptance

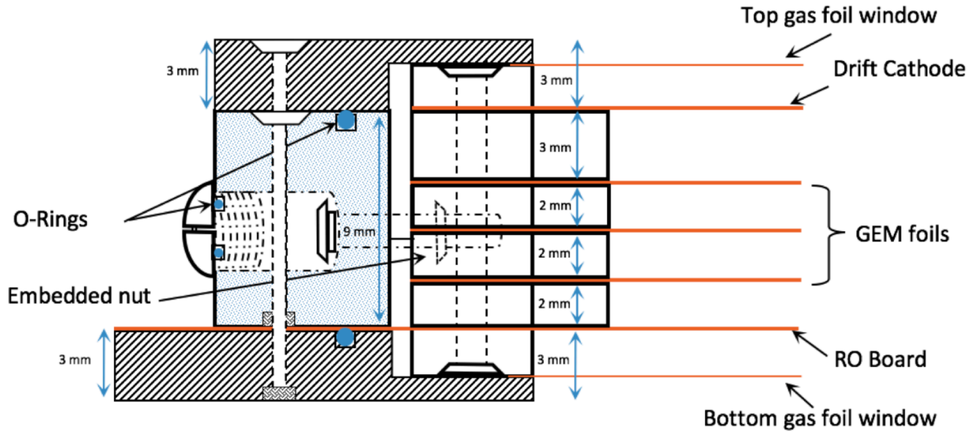


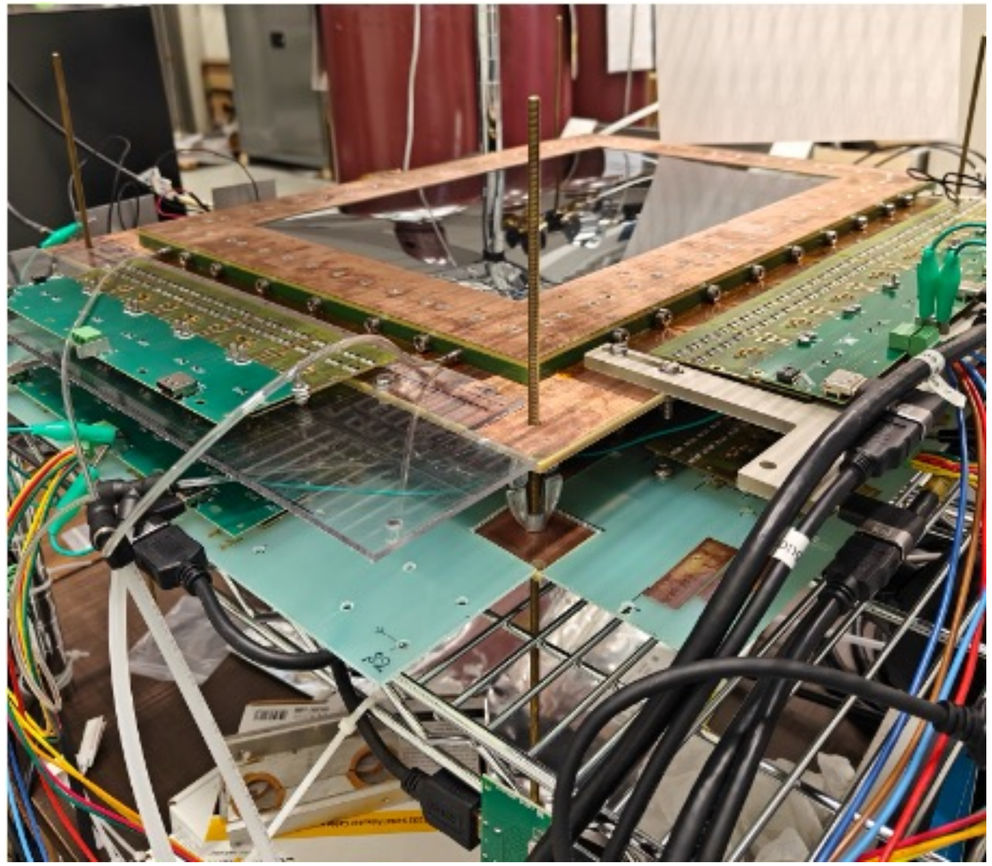
± 5° out of plane acceptance

± 1.5° in plane acceptance

GEMs

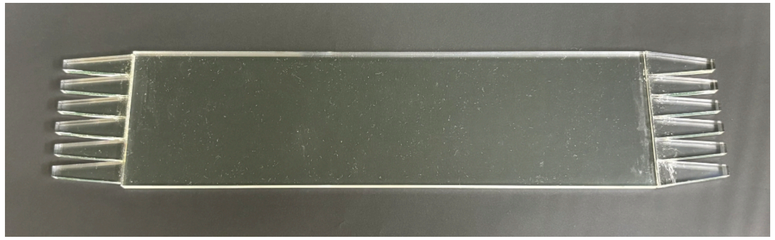
- **G**as **E**lectron **M**ultipliers
- Tracking detectors to be used to reconstruct the 4 vectors for the electrons and positrons
- Preexisting 25 cm x 40 cm triple-GEMs built by Hampton University
- 400 μm strip pitch
- APV cards with MPD4 readout
- Positional resolution of around 100 microns
- Readout time of around 200 μs

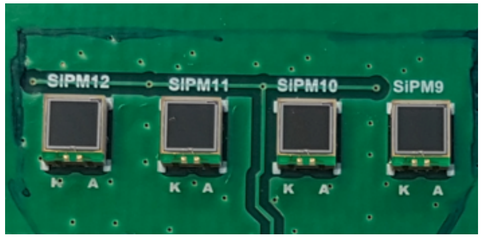




Triggers

- Eight fast plastic scintillator bars on each spectrometer arm
- Light guides couple to SiPMs

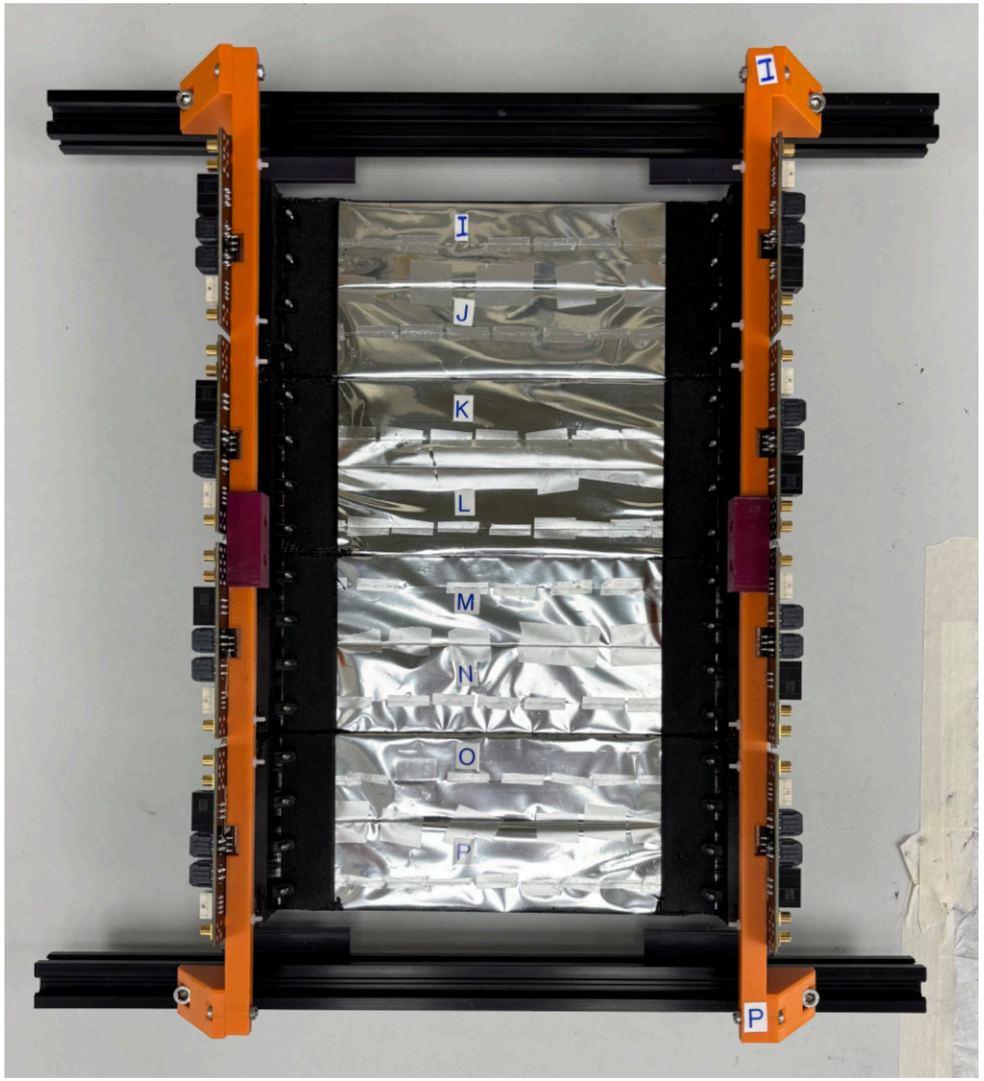




- Readout boards contain 12 SiPMs each and accommodate two bars
- Timing resolution of less than 500 ps required to resolve individual electron bunches
  - Final time resolution around 380 ps
- Can also determine position with a resolution of around 2 cm
  - Helps with rejecting rare multi-hit events

Triggers

- Eight fast plastic scintillator bars on each spectrometer arm
- Light guides couple to SiPMs



- Readout boards contain 12 SiPMs each and accommodate two bars
- Timing resolution of less than 500 ps required to resolve individual electron bunches
  - Final time resolution around 380 ps
- Can also determine position with a resolution of around 2 cm
  - Helps with rejecting rare multi-hit events