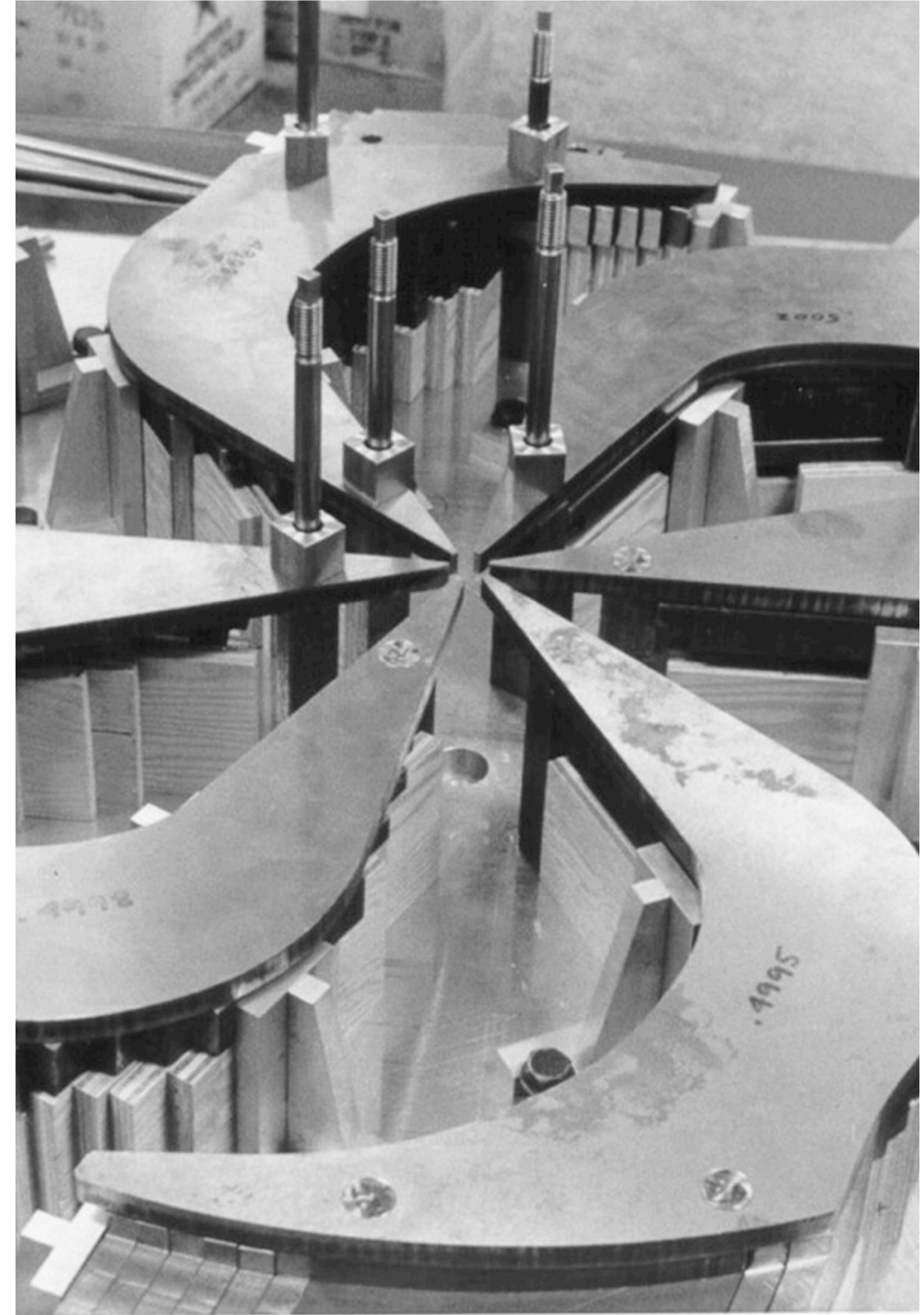




# Shedding light on the dark sector with DarkLight

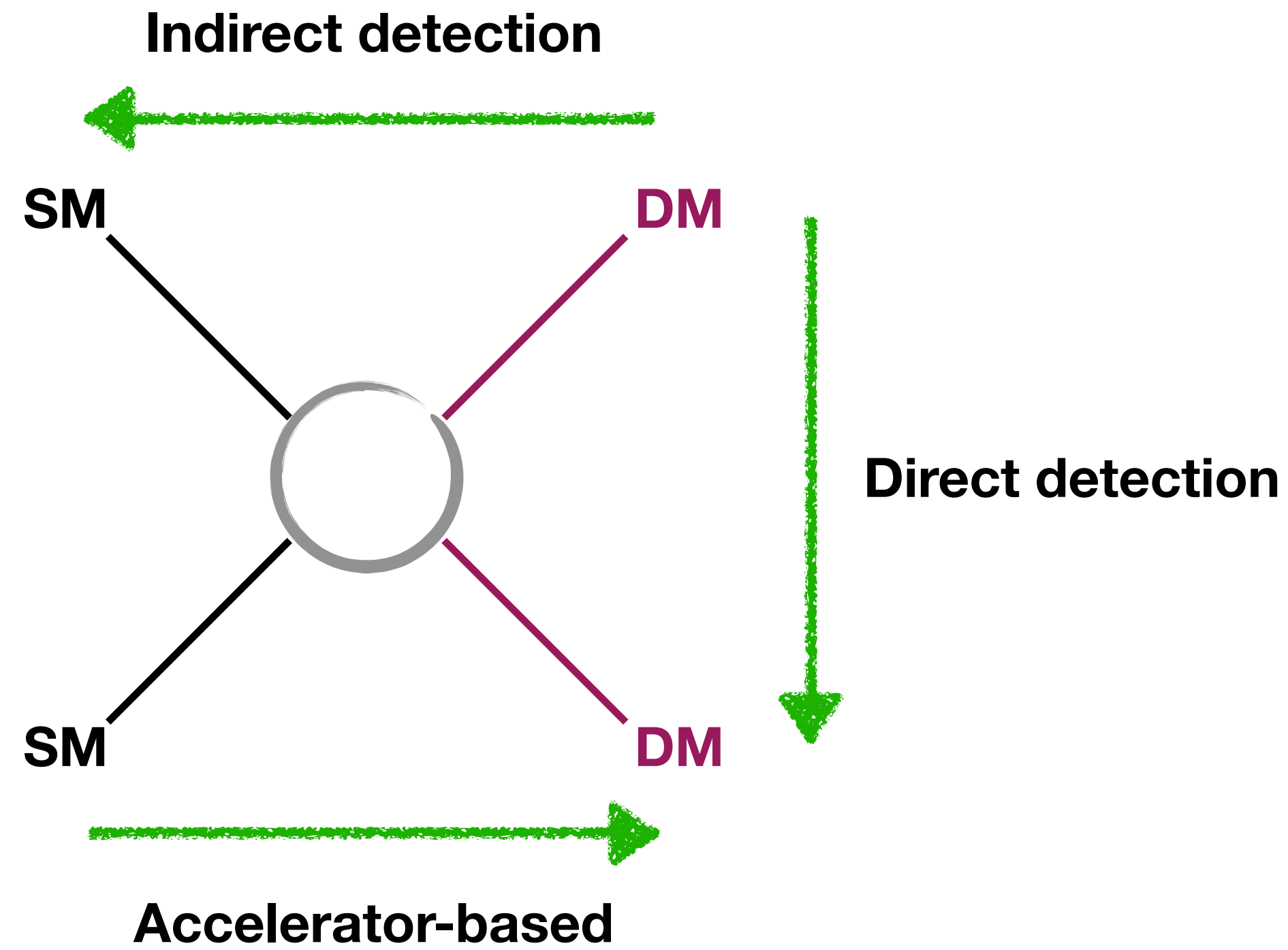
Laura Miller

CAP Congress 2026  
2026-06-23



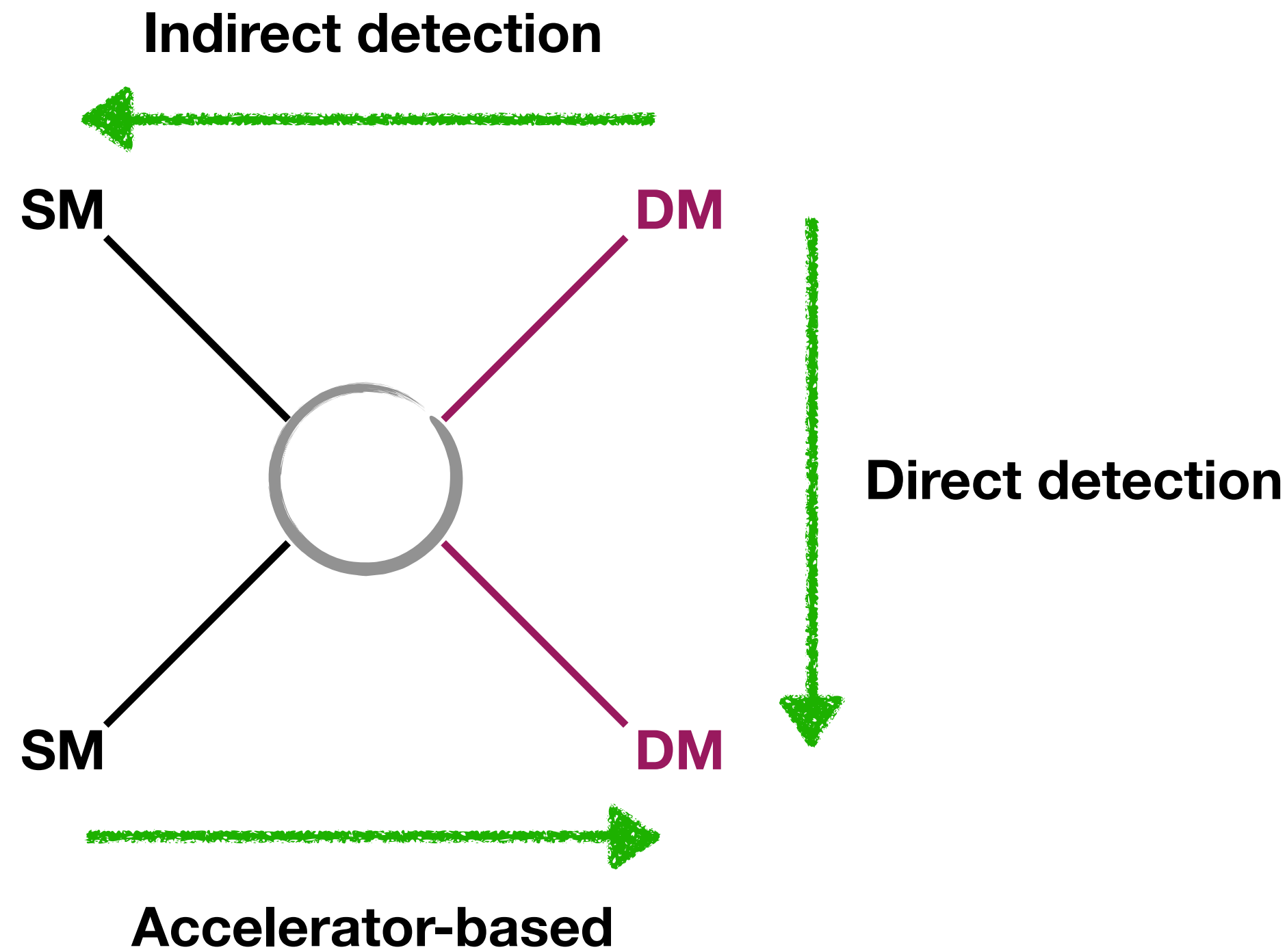
**Discovery,  
accelerated**

# Dark Matter Searches

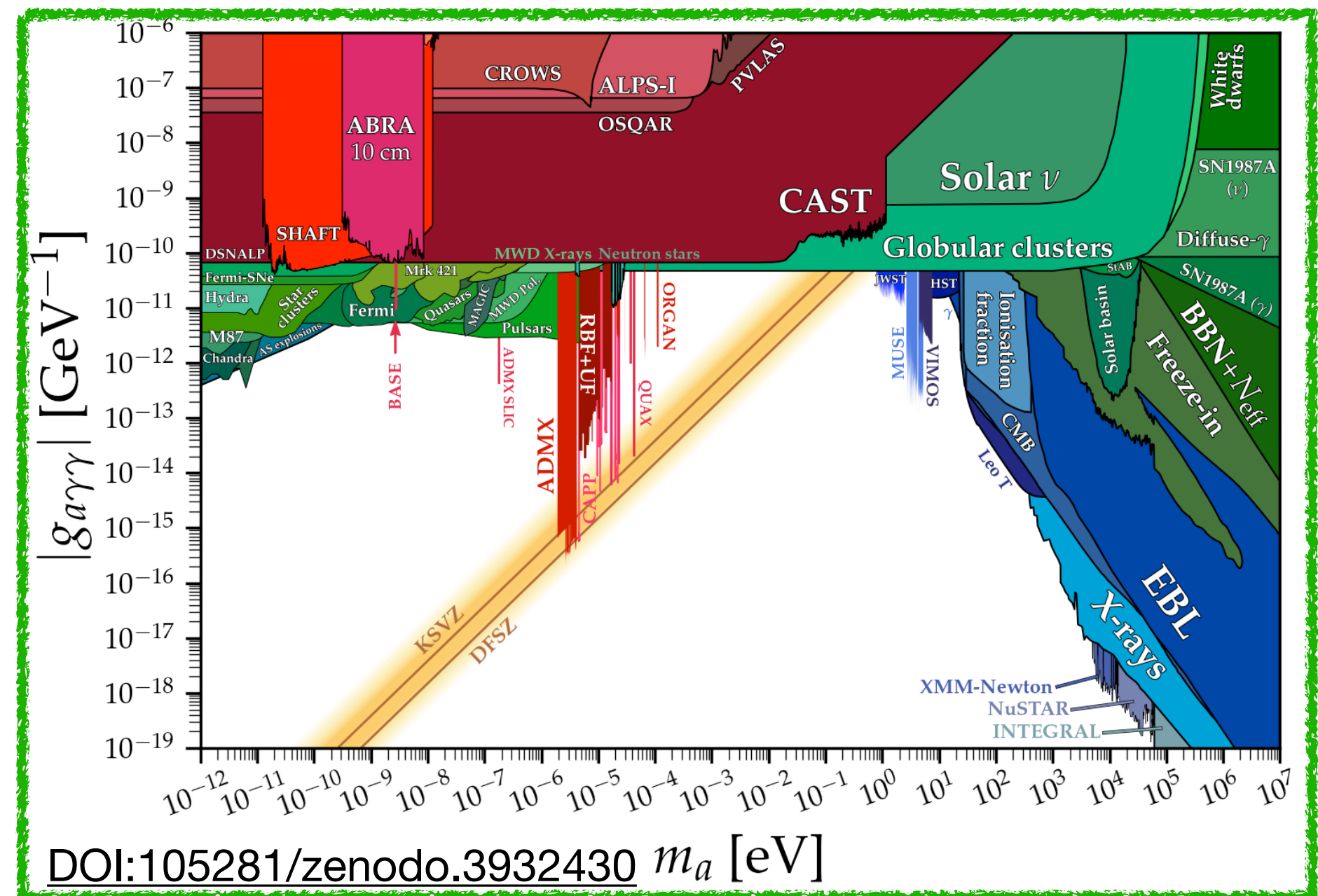
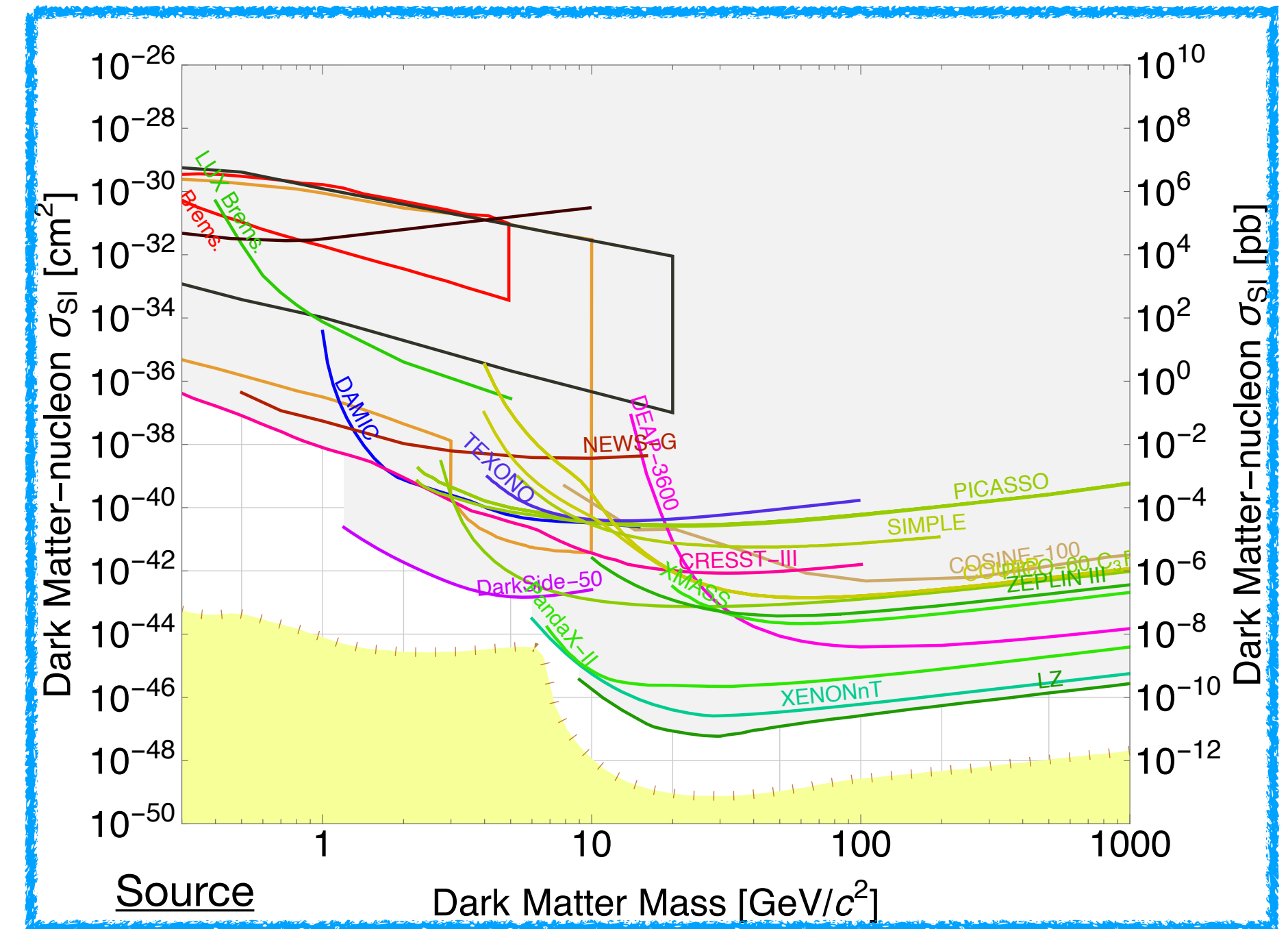


- Many, many searches performed over the years

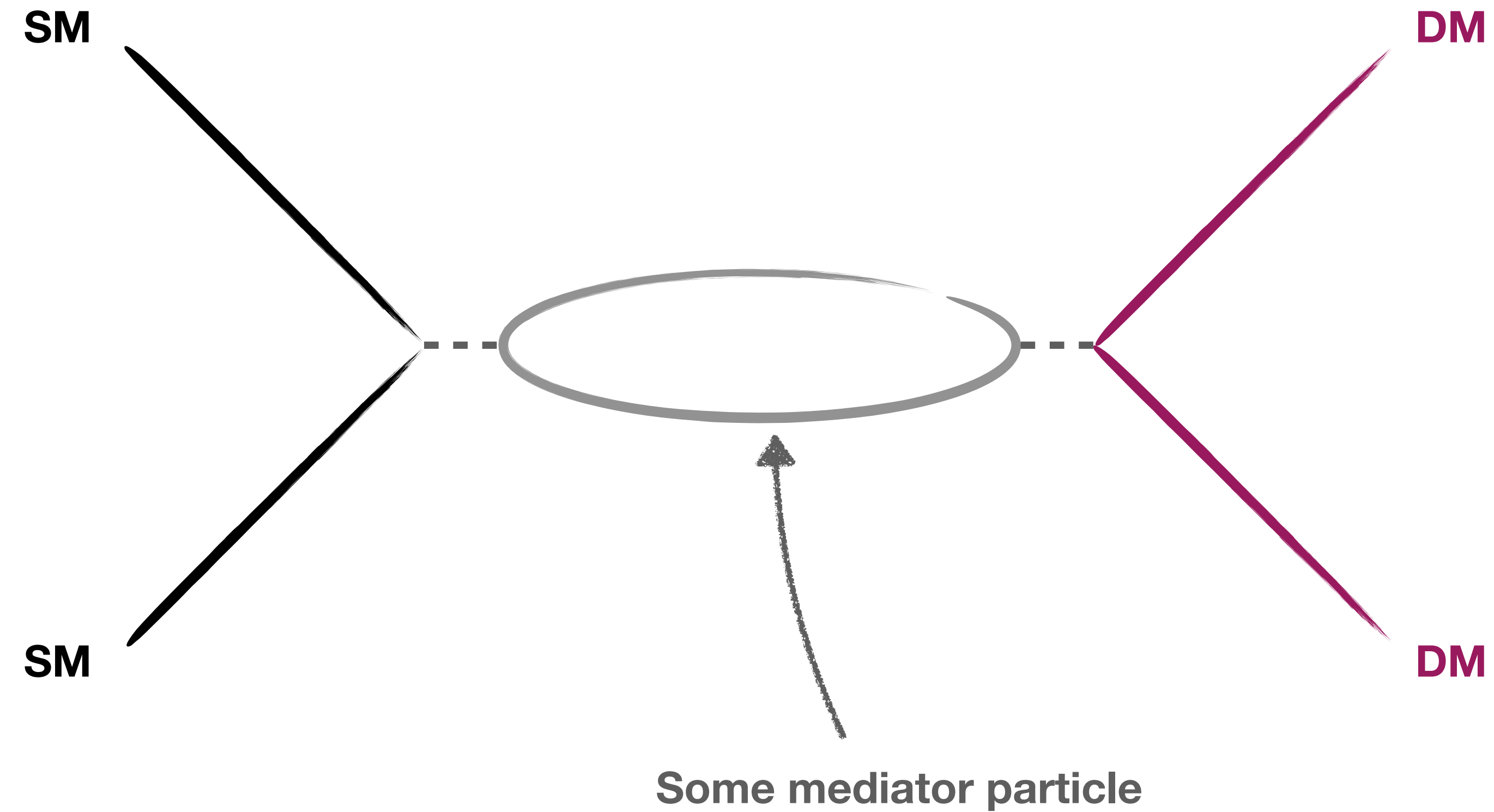
# Dark Matter Searches



- Many, many searches performed over the years
- Large historical focus on weakly interacting massive particles (WIMPs) and axions
- No evidence found so far



# Dark Sector Models

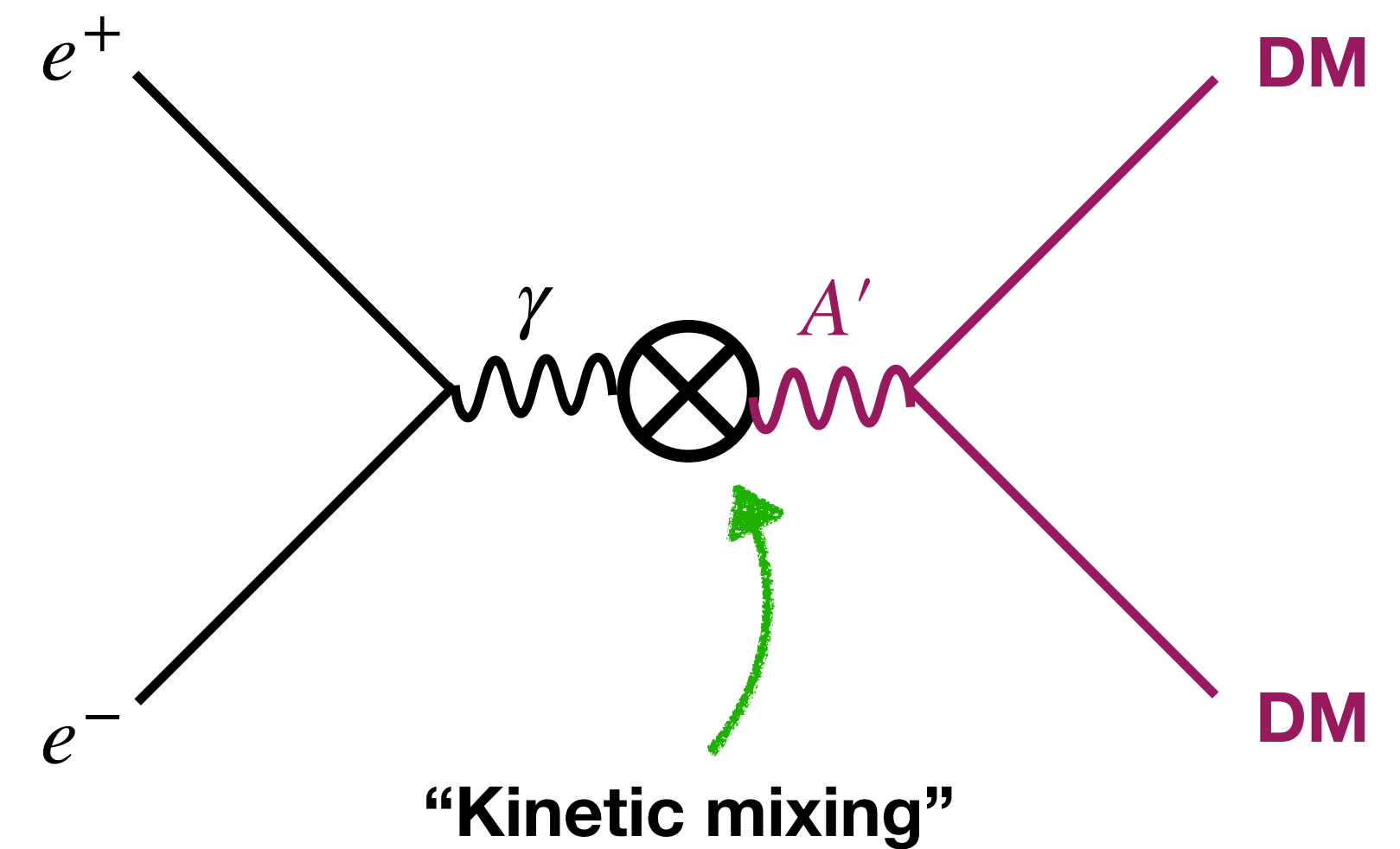


- Posits a dark sector not charged under an SM gauge group, where interactions with the SM are facilitated by an intermediary particle

# 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

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

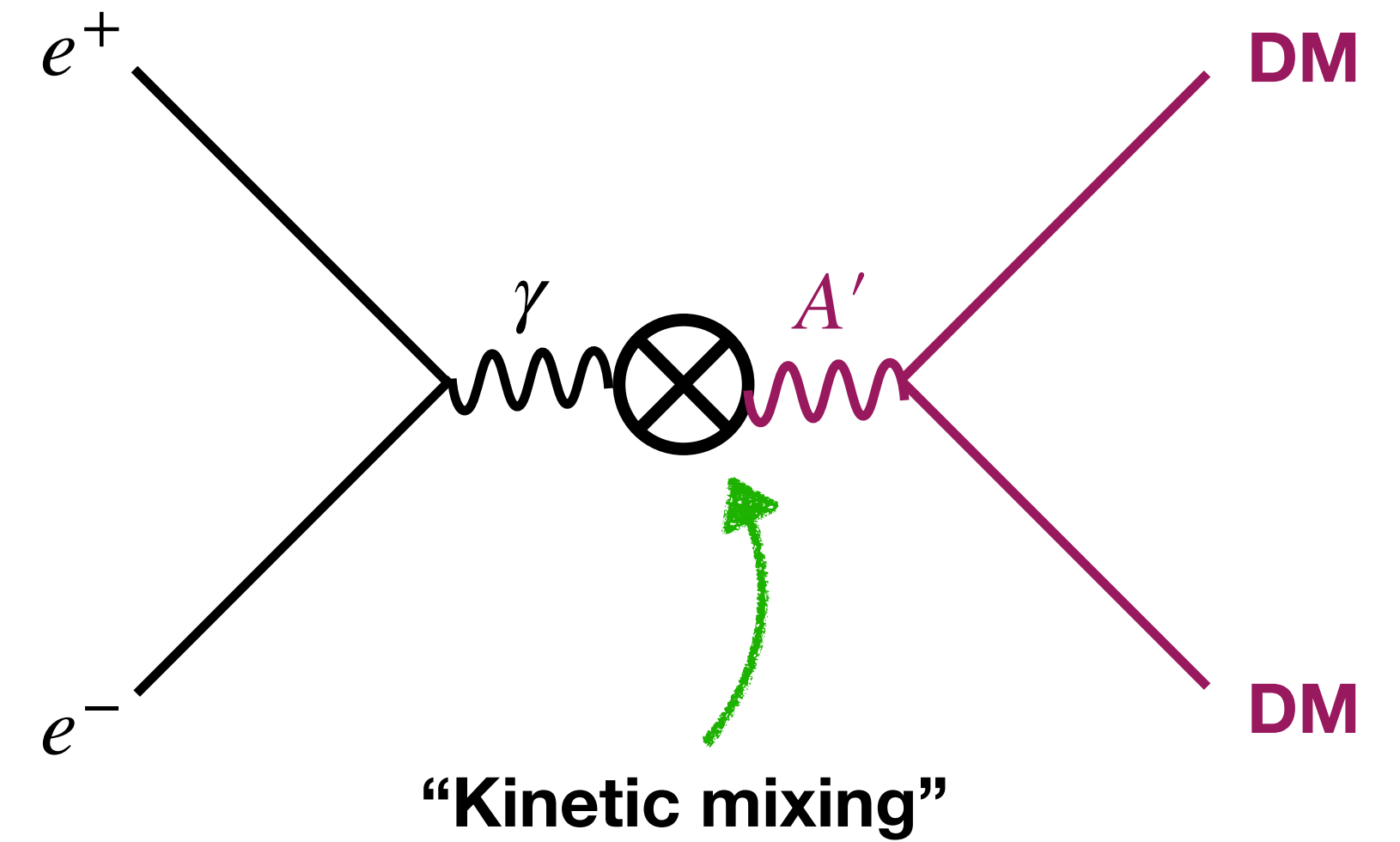


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$$\mathcal{L}_{\text{int}} = e\epsilon J_{\mu} A'^{\mu}$$

Kinetic mixing strength  $\epsilon$  (blue arrow)  
SM QED current  $J_{\mu}$  (green arrow)  
Dark photon  $A'^{\mu}$  (purple arrow)



# Dark Photon Model

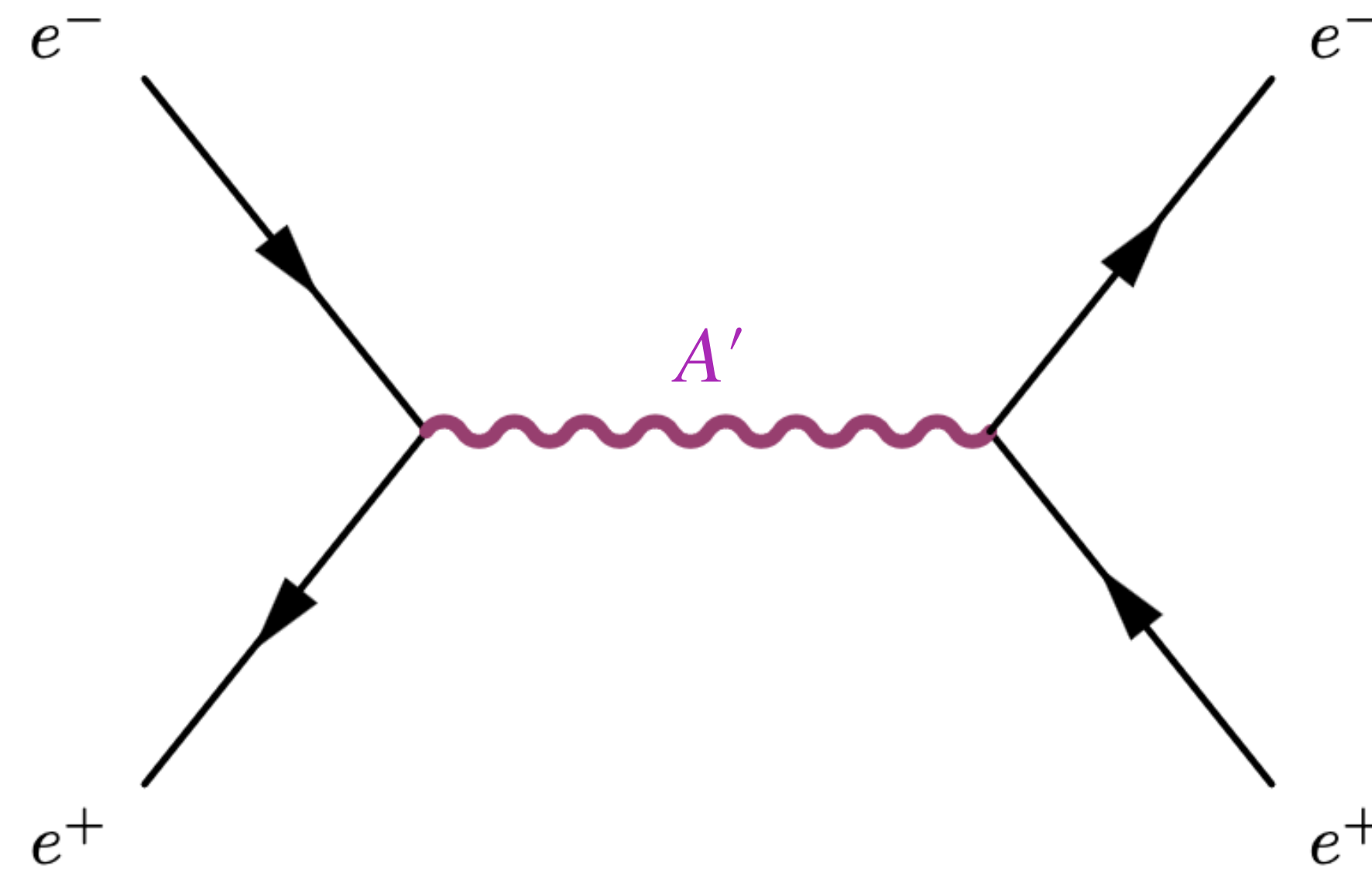
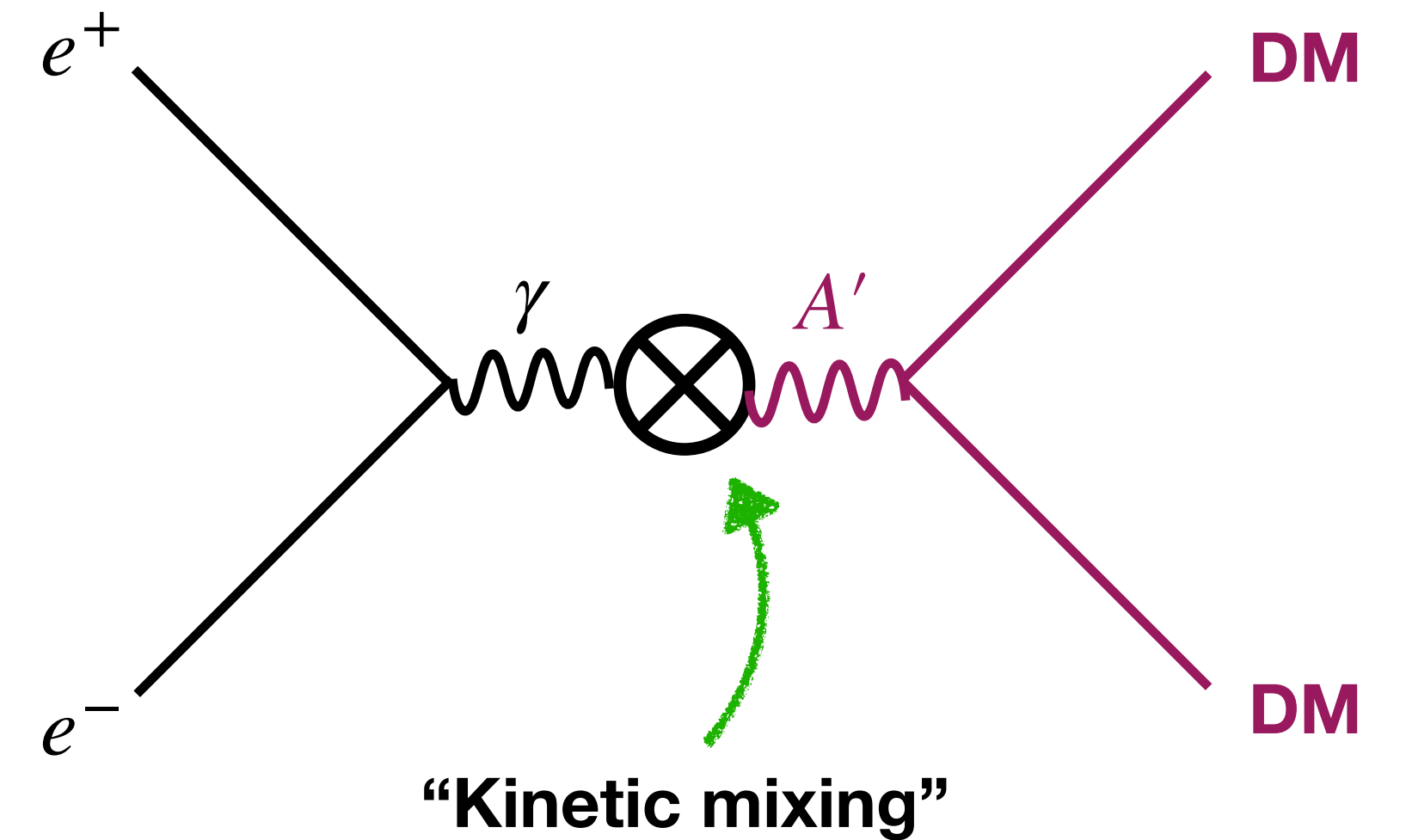
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Kinetic mixing strength

Dark photon

SM QED current



# Dark Photon Model

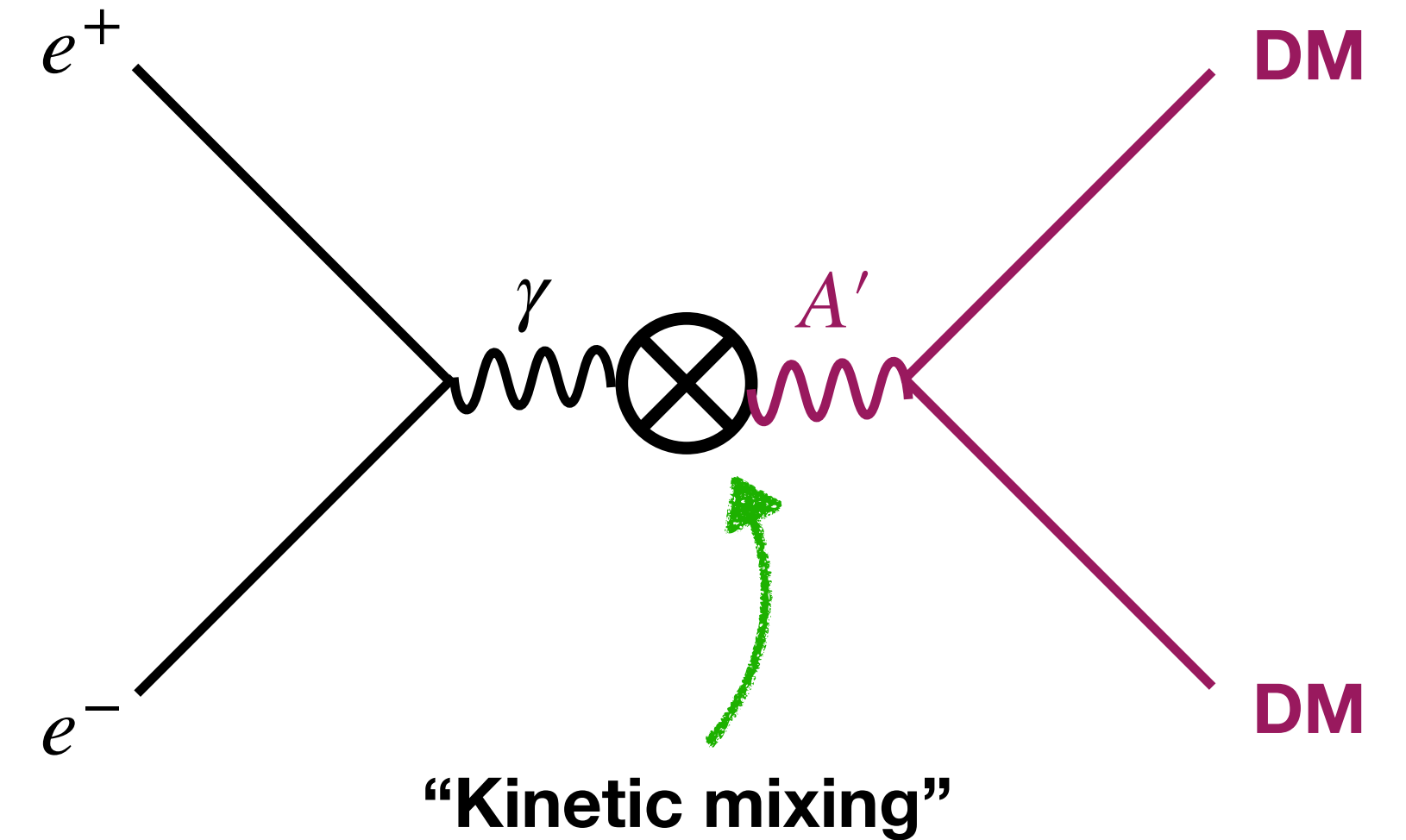
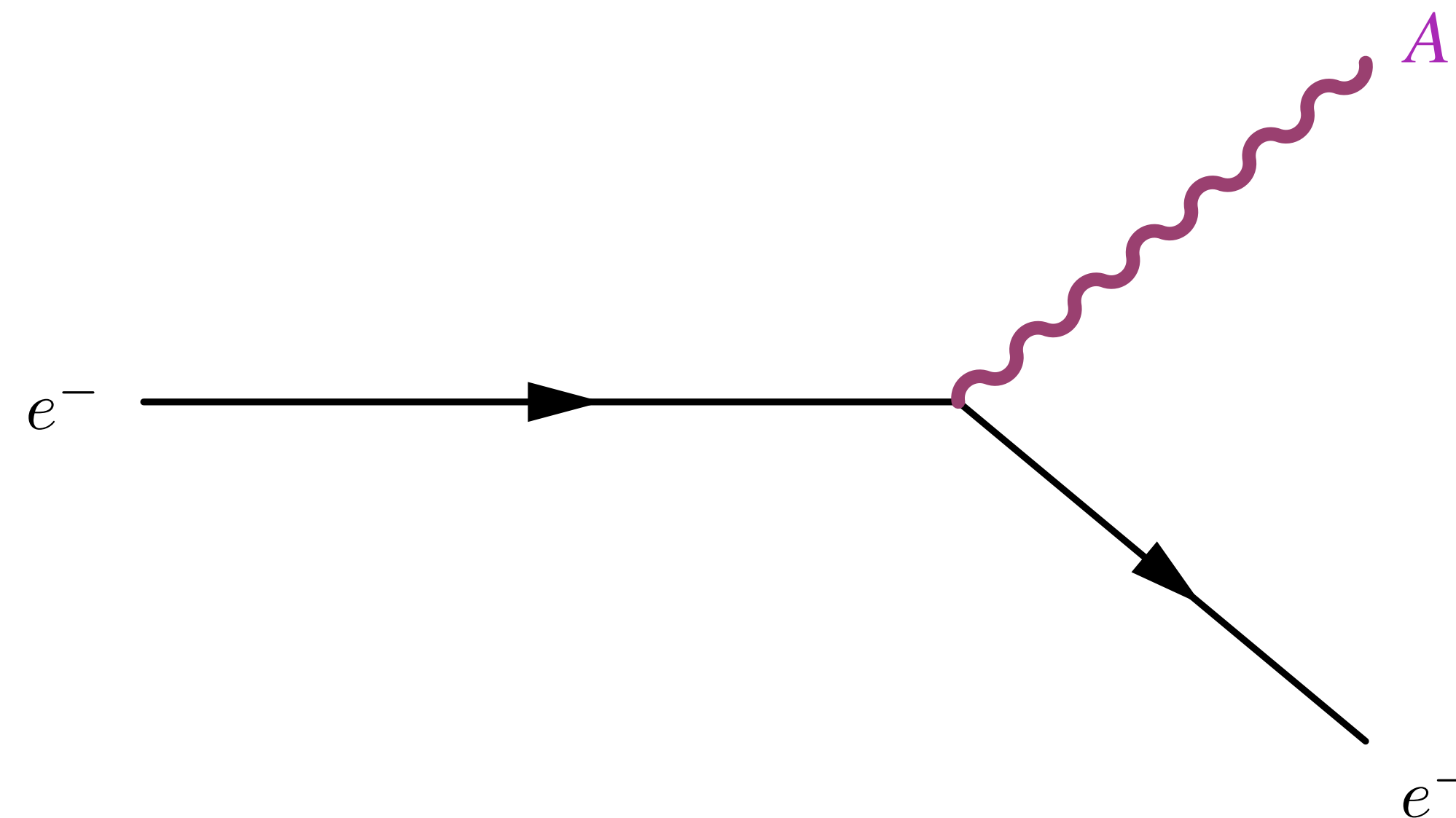
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Kinetic mixing strength

Dark photon

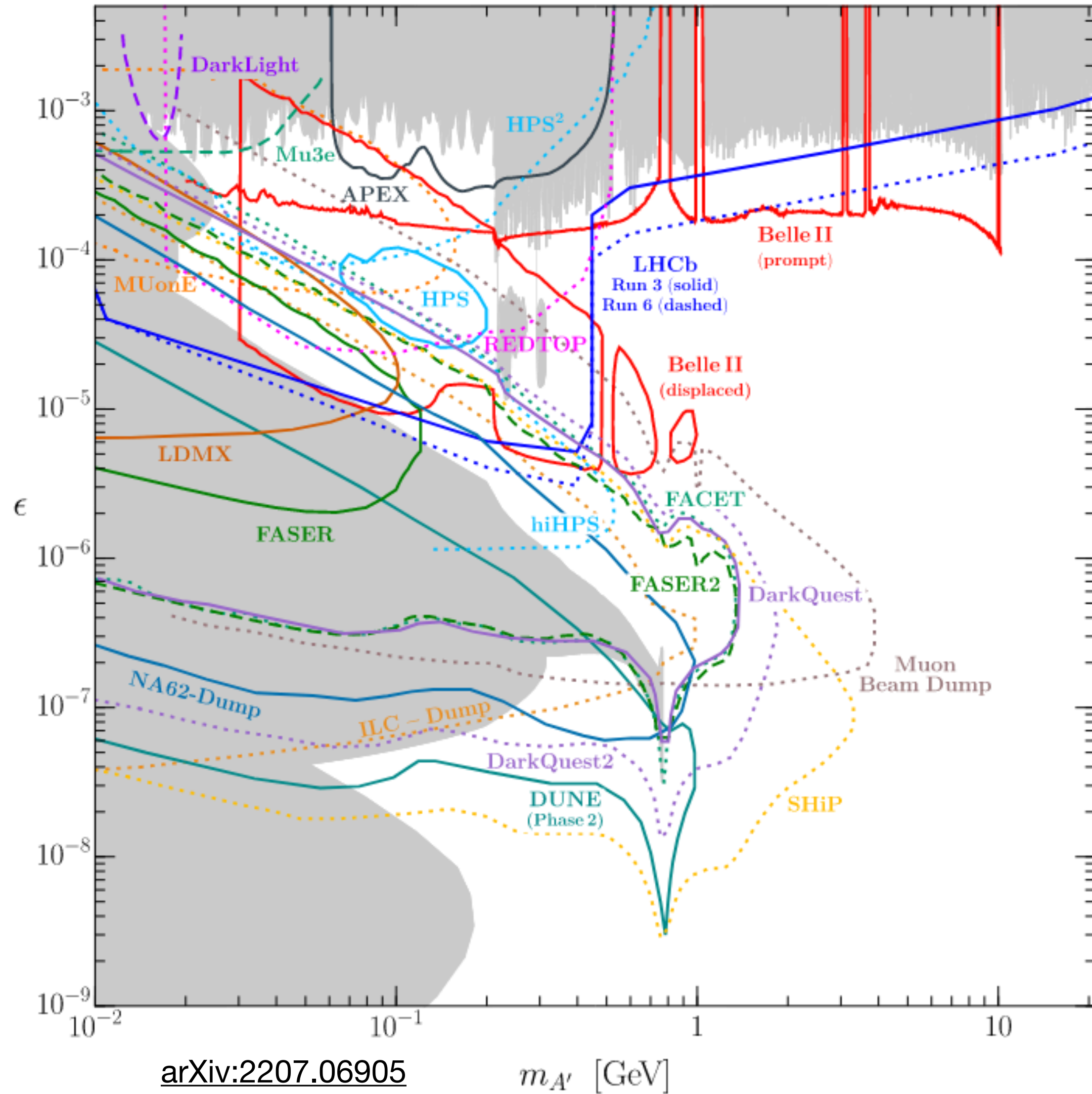
SM QED current



# Dark Photons: Current Limits

Limits for past (grey) and future dark photon experiments

5

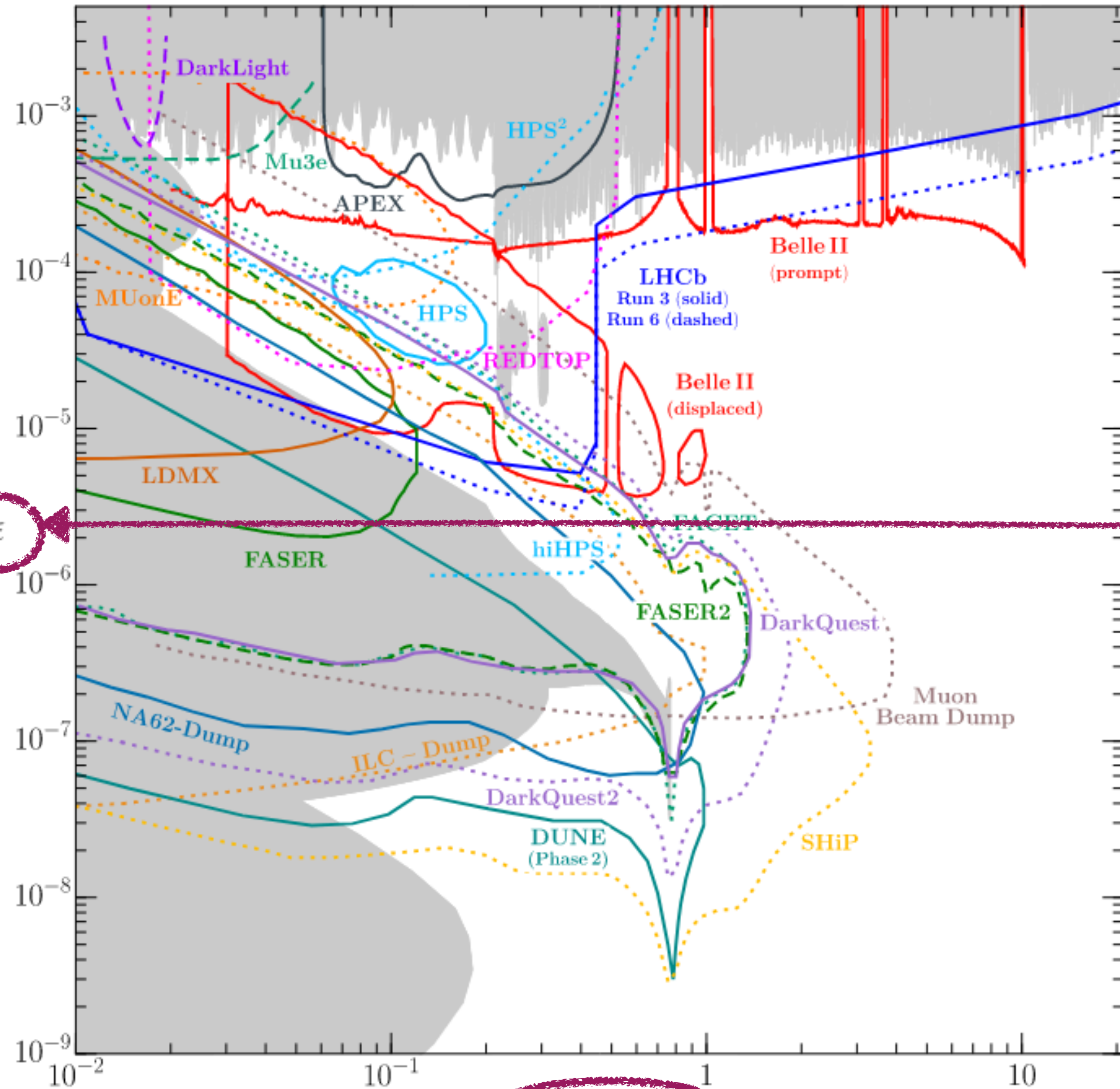


# Dark Photons: Current Limits

Higher energy

Limits for past (grey) and future dark photon experiments

5



arXiv:2207.06905

$m_{A'}$  [GeV]

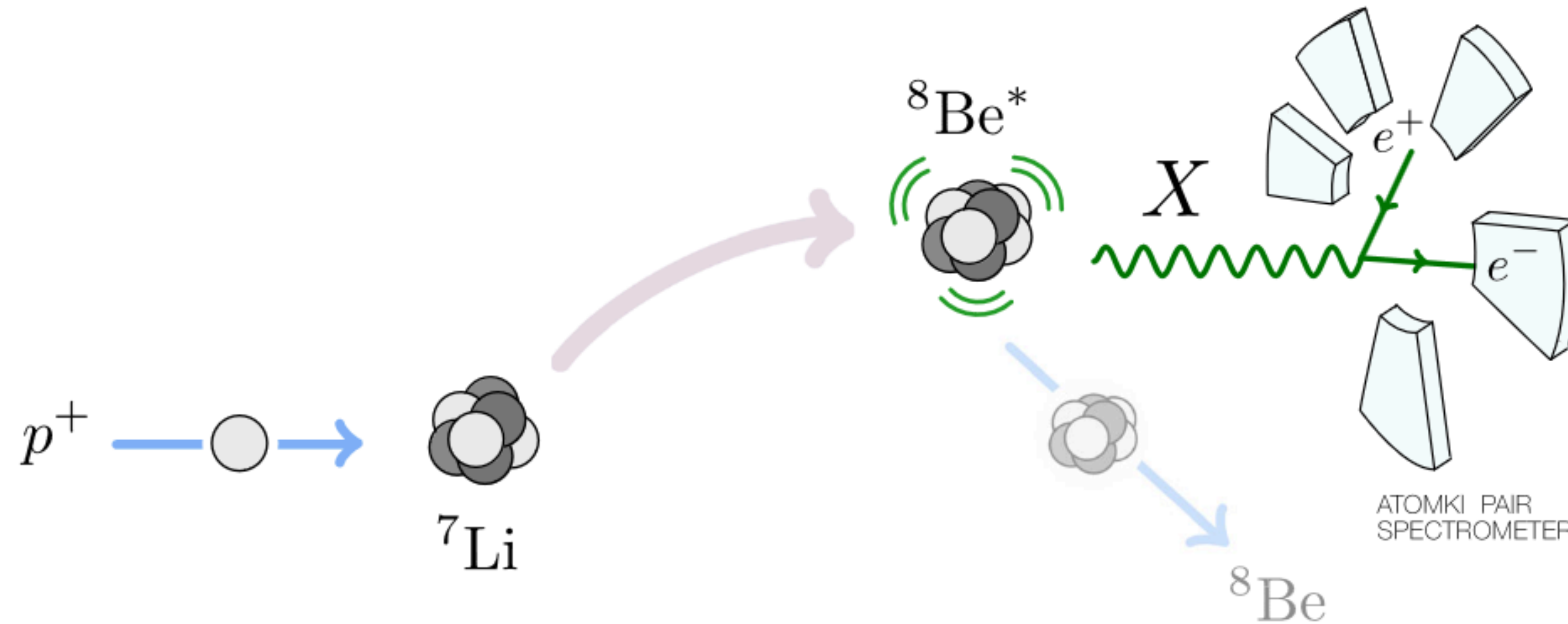
Kinetic mixing strength

Dark photon mass

# Experimental Anomalies: X17

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

6



Physical Review D 95, 035017 (2017)

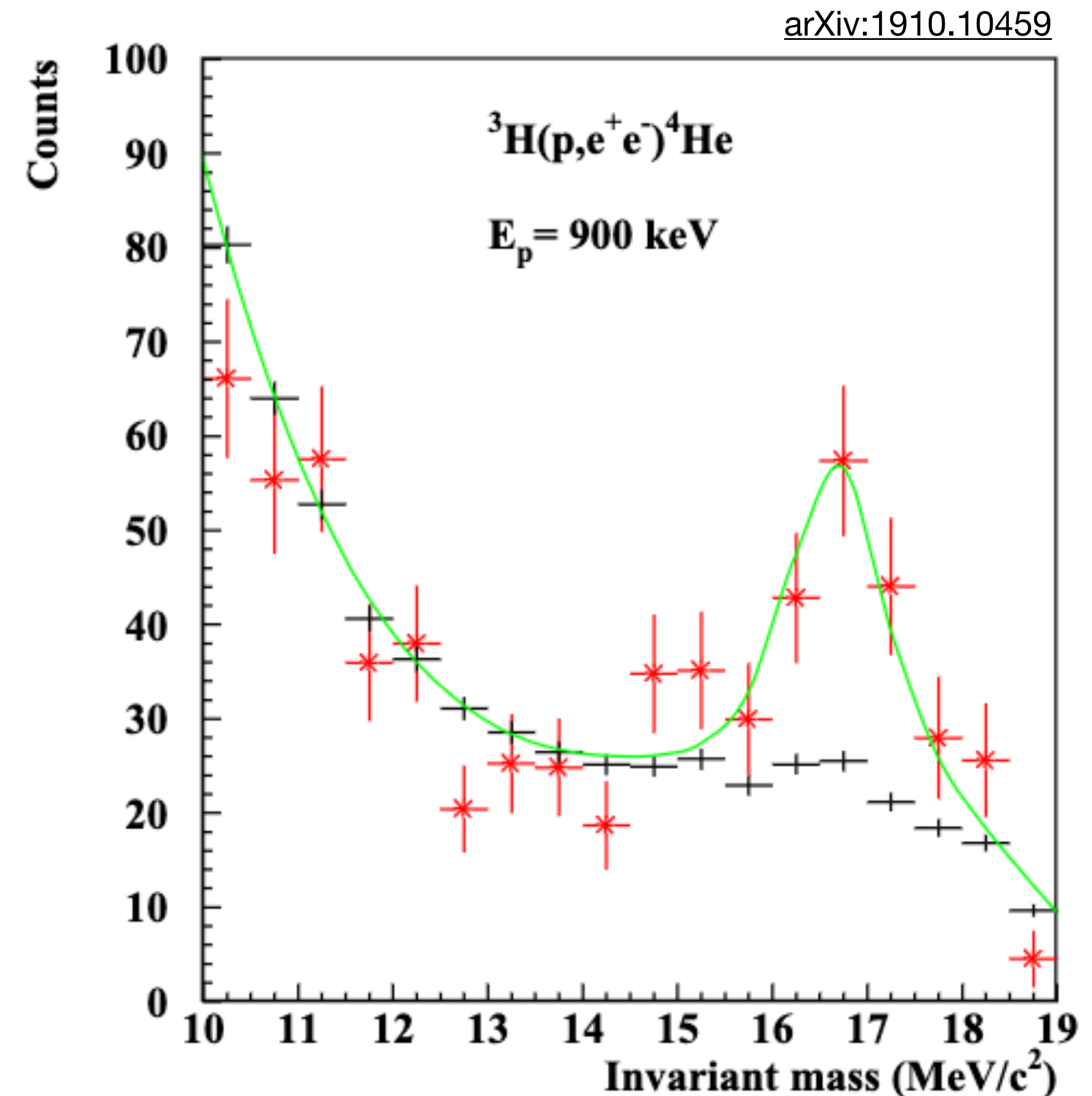
See: [Phys. Rev. Lett. 116, 042501 \(2016\)](#), [arXiv:1910.10459](#), [Phys. Rev. C 104, 044003 \(2021\)](#),

[arXiv:2205.07744](#), [Phys. Rev. C 106, L061601 \(2022\)](#), [arXiv:2308.06473](#), [arXiv:2311.18632](#), [arXiv:2401.11676](#)

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6



See: [Phys. Rev. Lett. 116, 042501 \(2016\)](#), [arXiv:1910.10459](#), [Phys. Rev. C 104, 044003 \(2021\)](#),

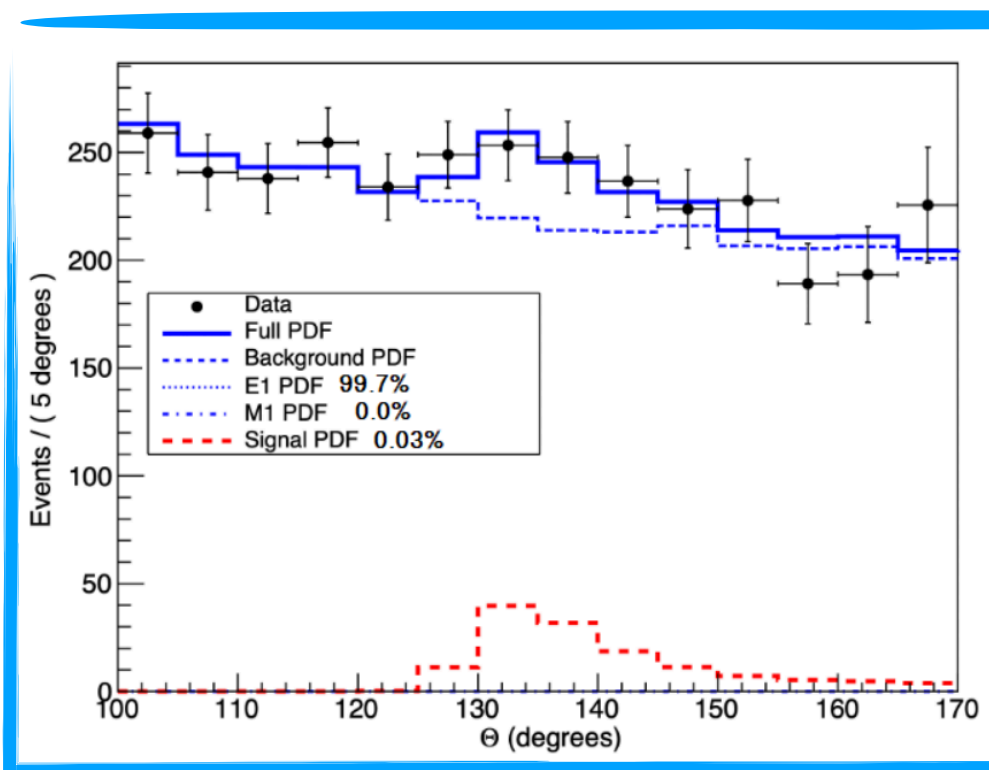
[arXiv:2205.07744](#), [Phys. Rev. C 106, L061601 \(2022\)](#), [arXiv:2308.06473](#), [arXiv:2311.18632](#), [arXiv:2401.11676](#)

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6

## Positive Observations



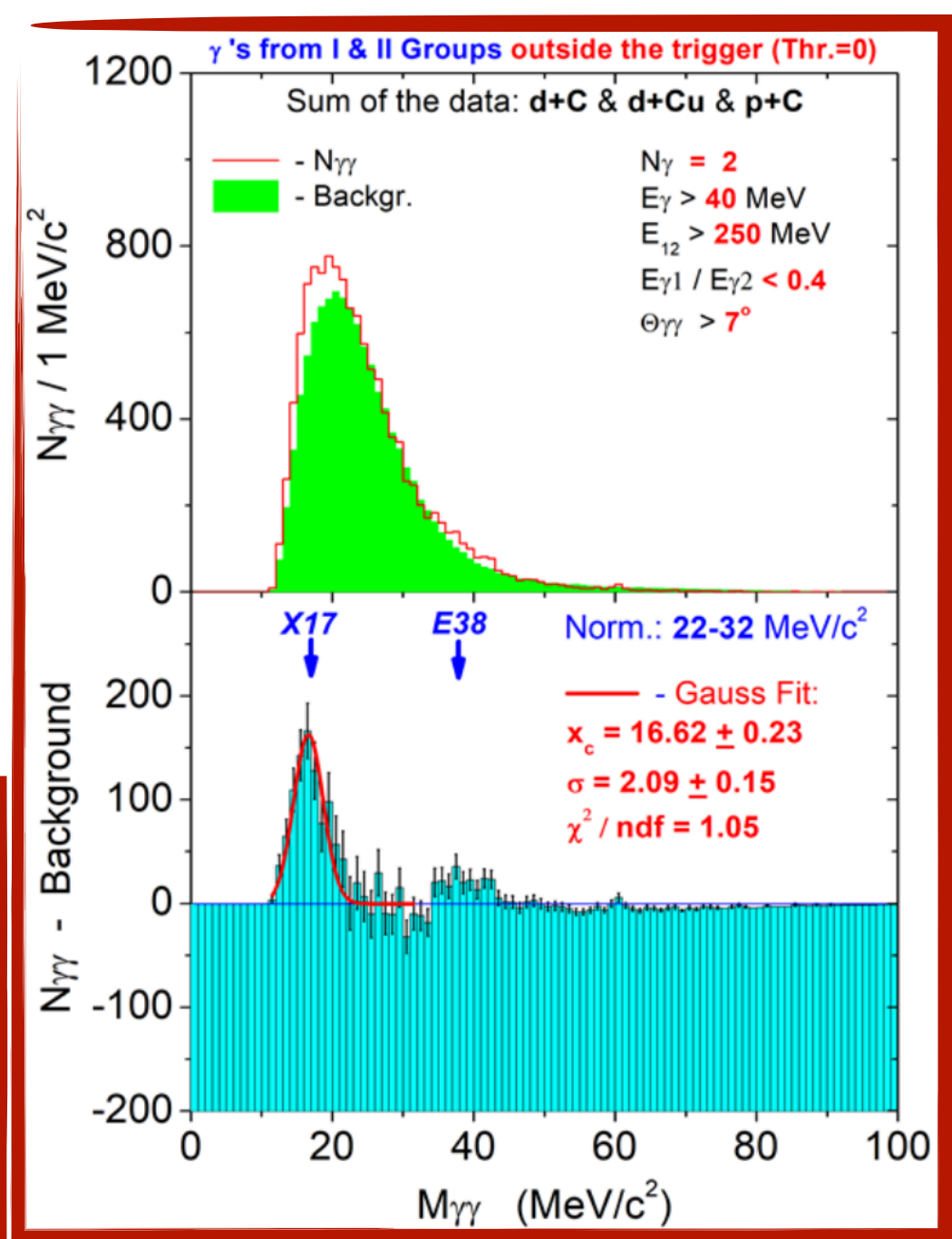
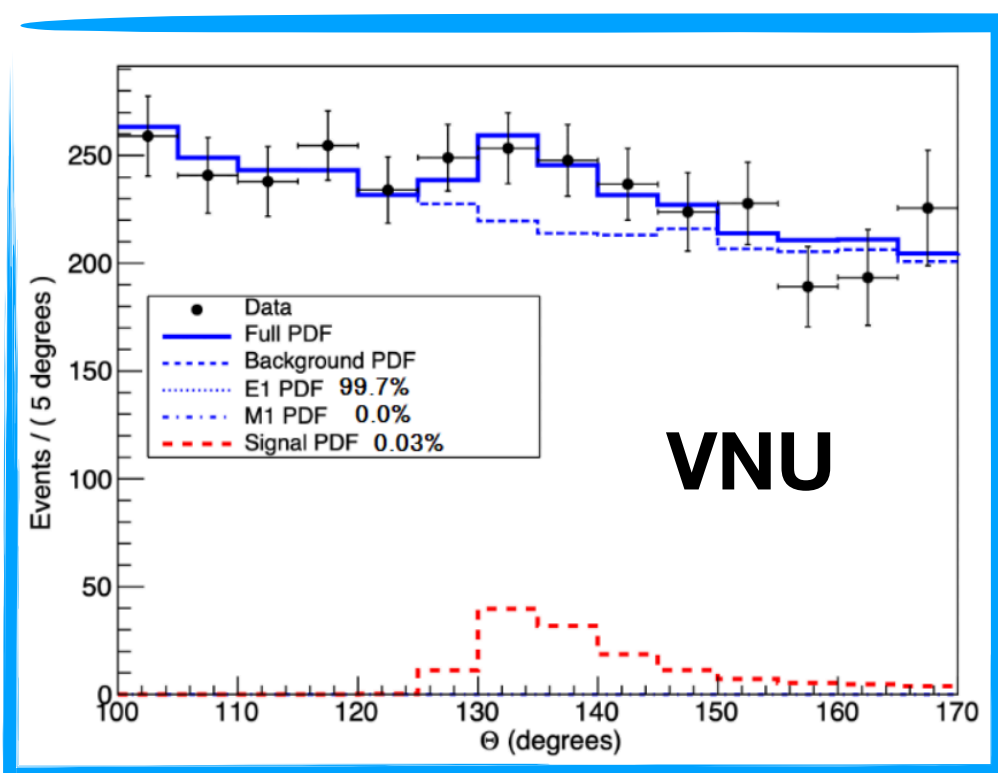
**VNU University of Science in Vietnam (arXiv:2401.1176): independent two arm spectrometer, with help from ATOMKI collaboration,  $4\sigma$  excess**

## Negative Observations

# Experimental Anomalies: X17?

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## Positive Observations



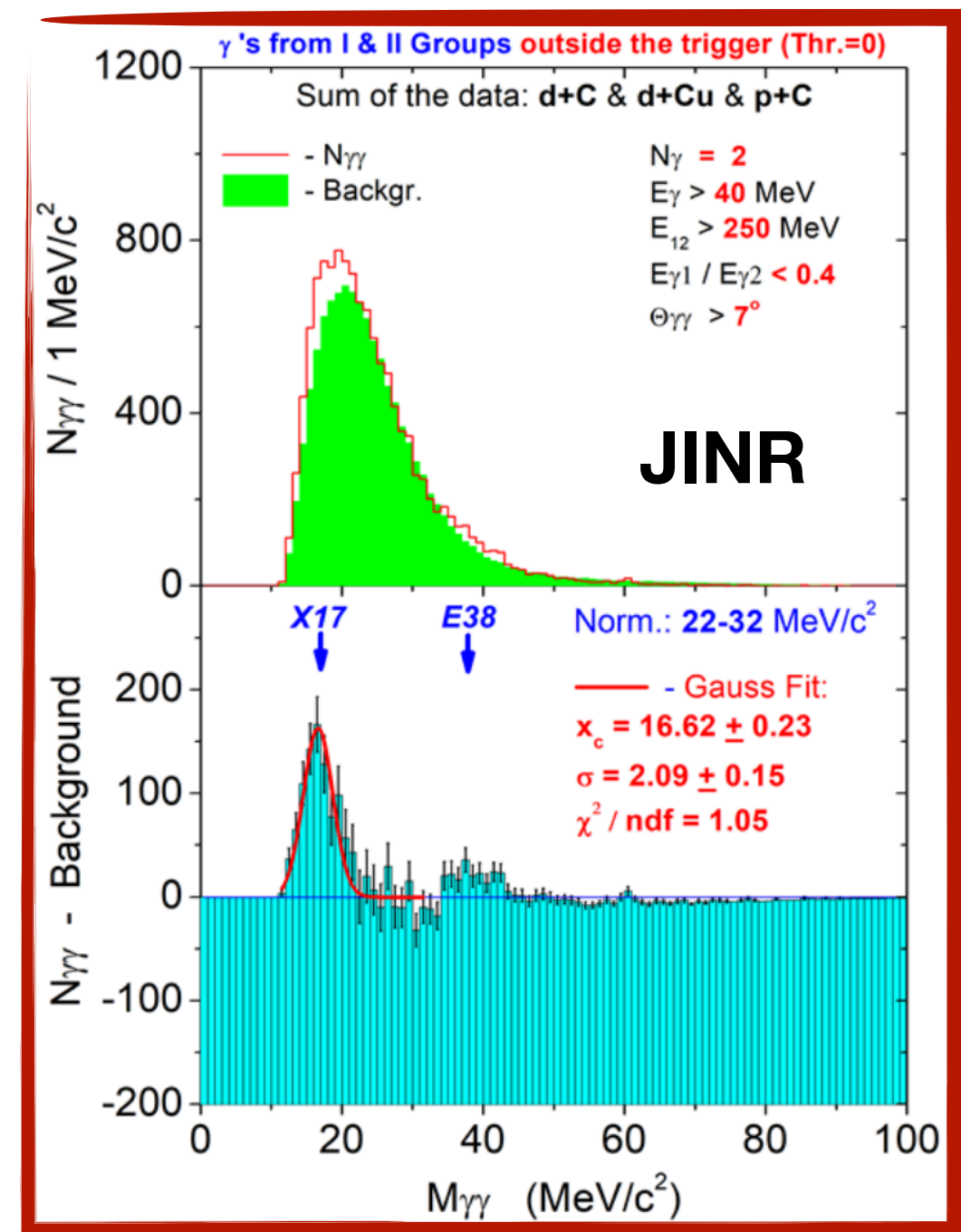
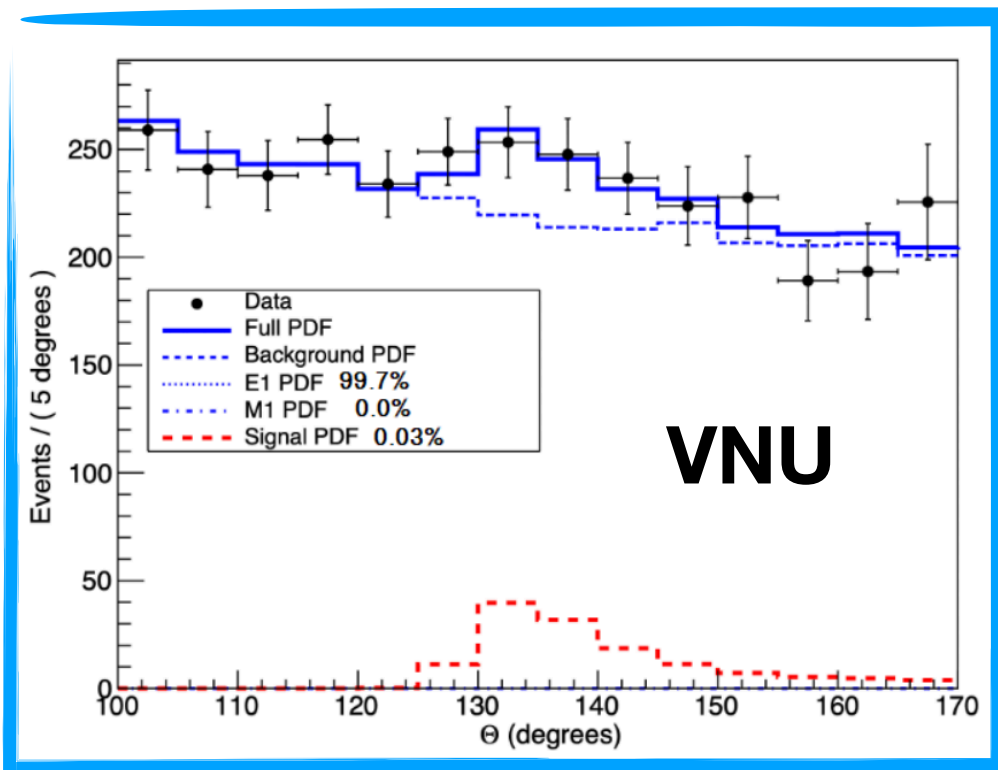
## Negative Observations

**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

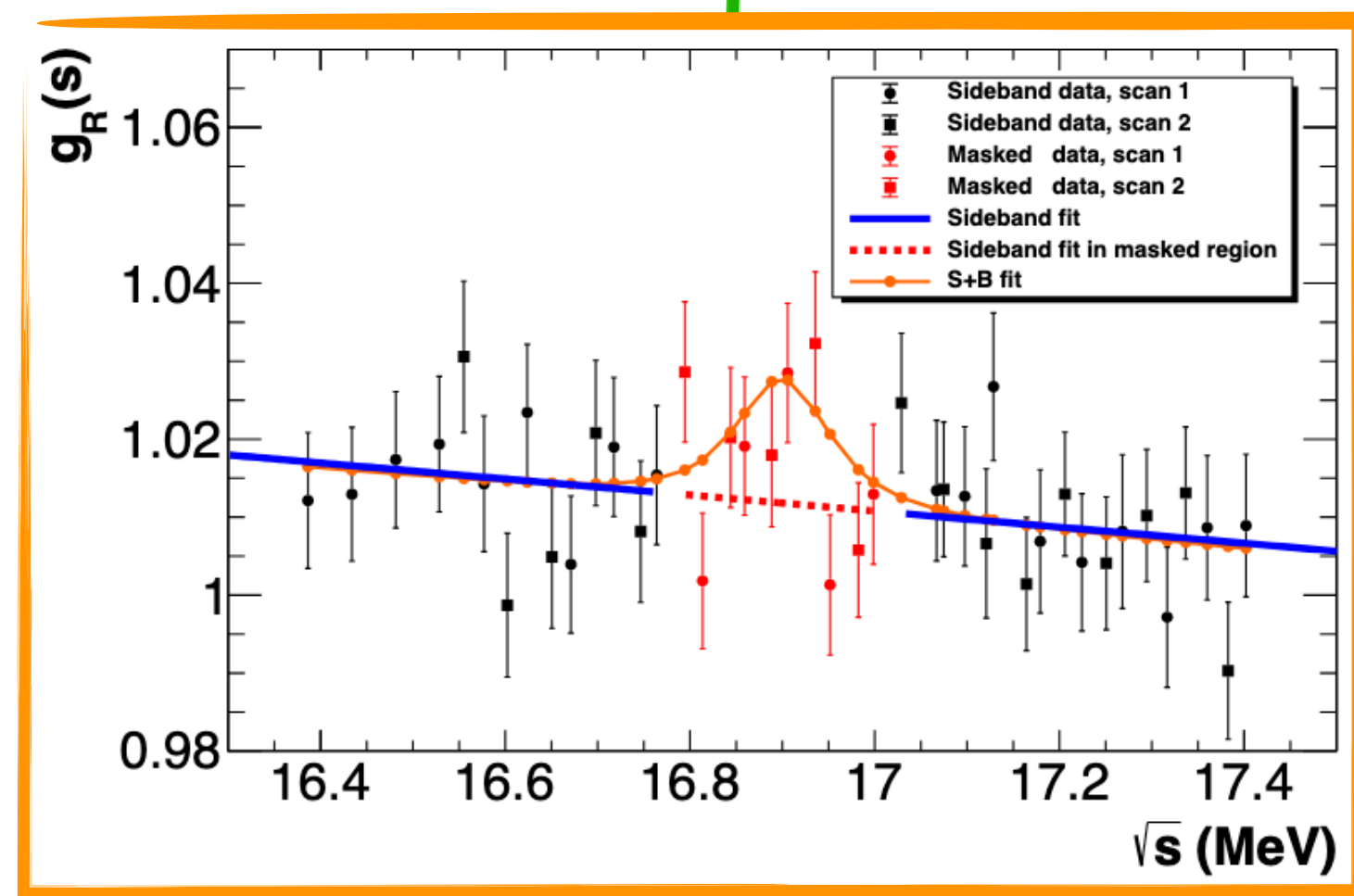
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## Positive Observations



## Negative Observations

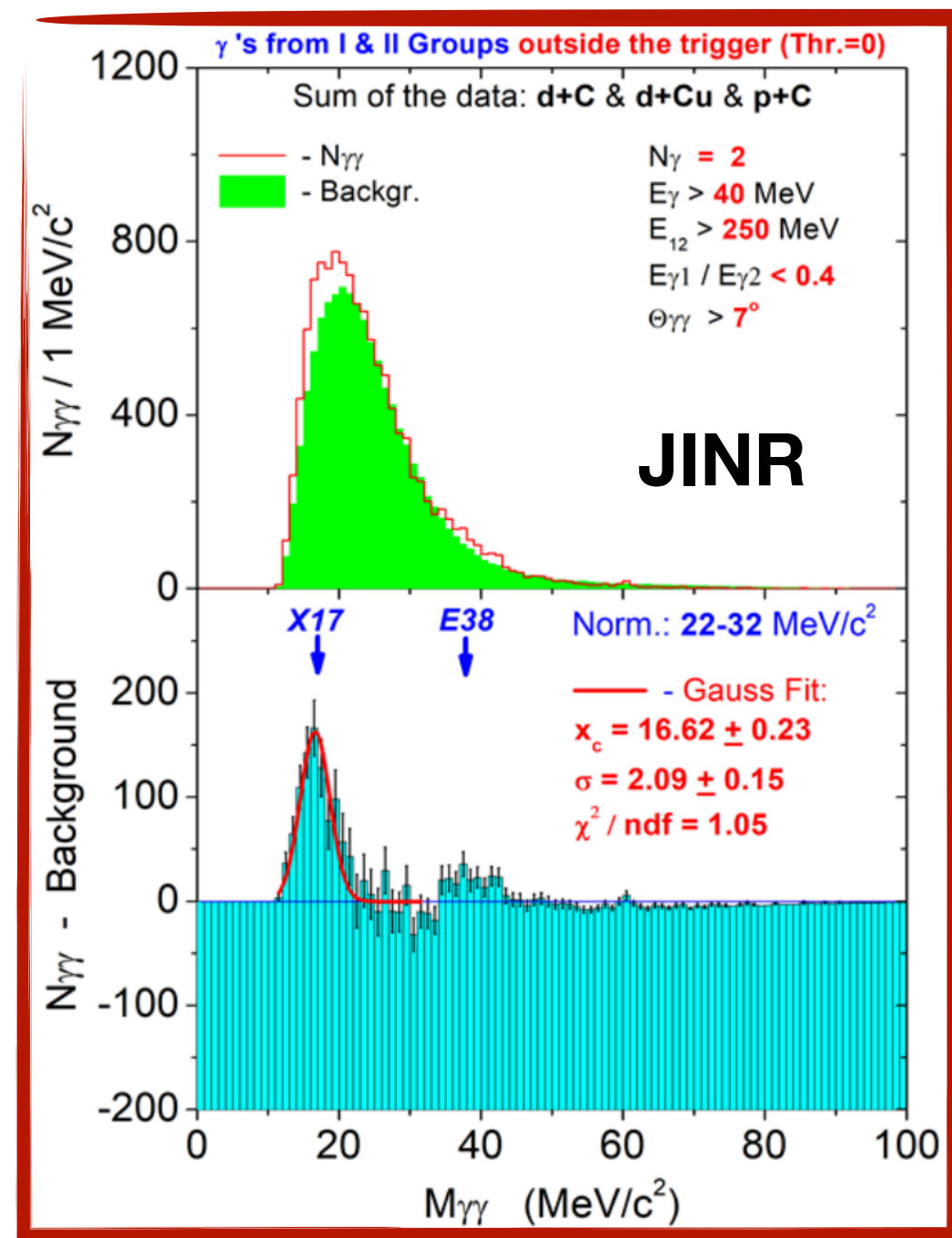
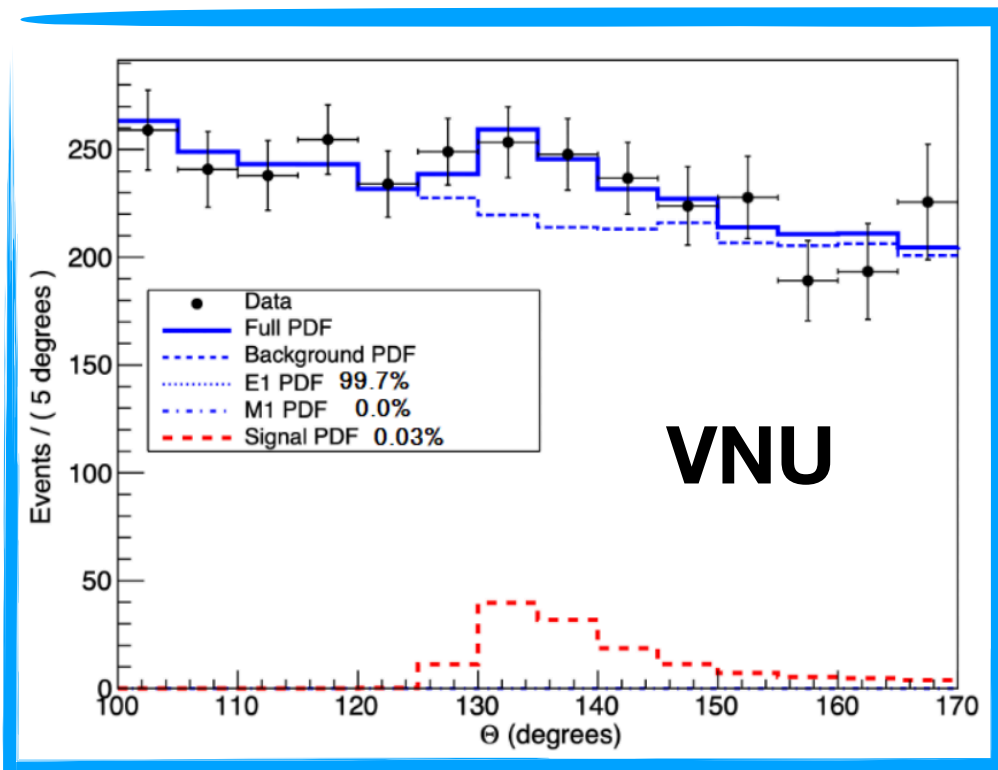


**PADME at INFN (arXiv:2505.24797): positron beam on fixed target, see roughly  $2\sigma$  significance over background**

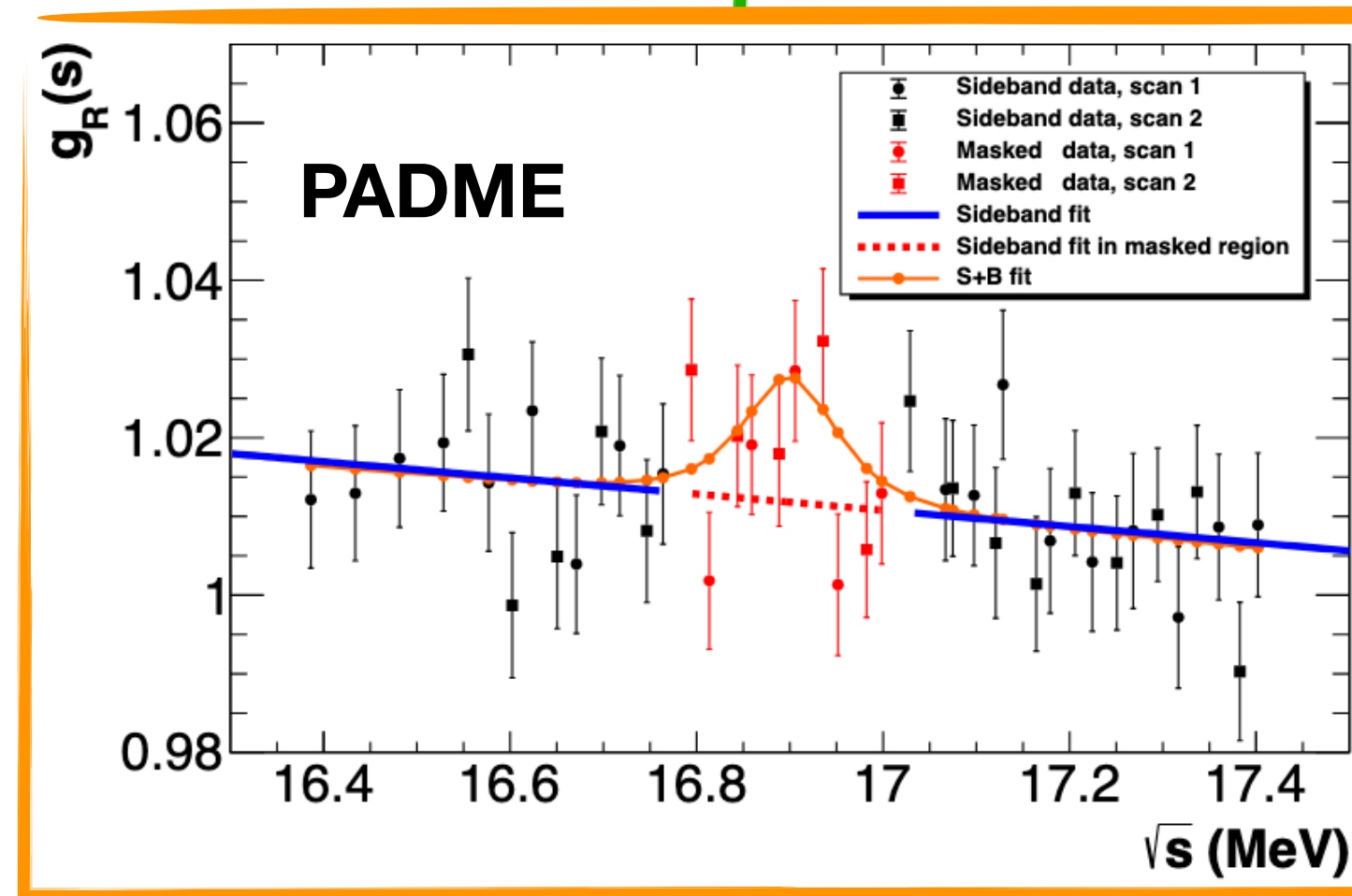
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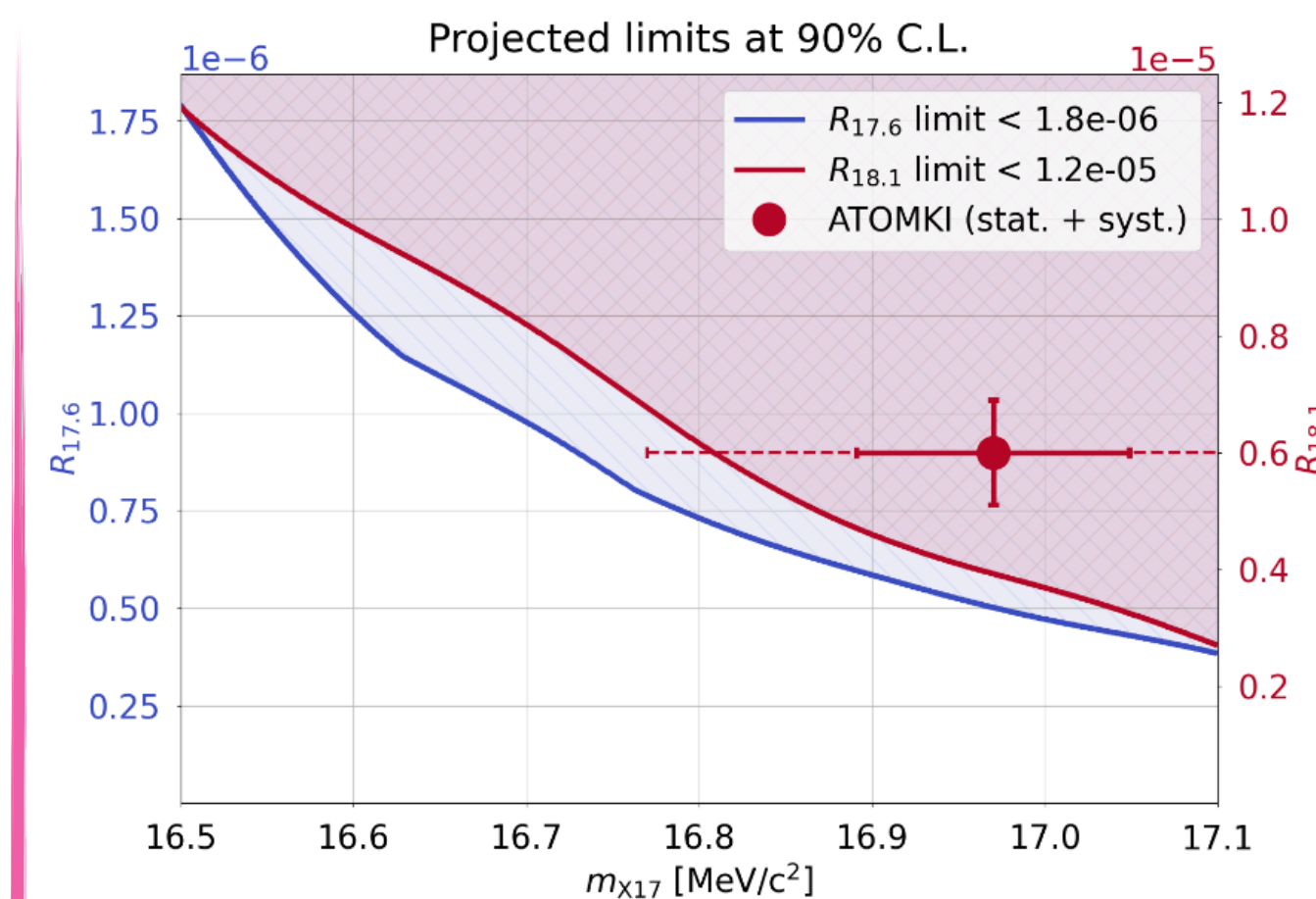
## Positive Observations



## Negative Observations



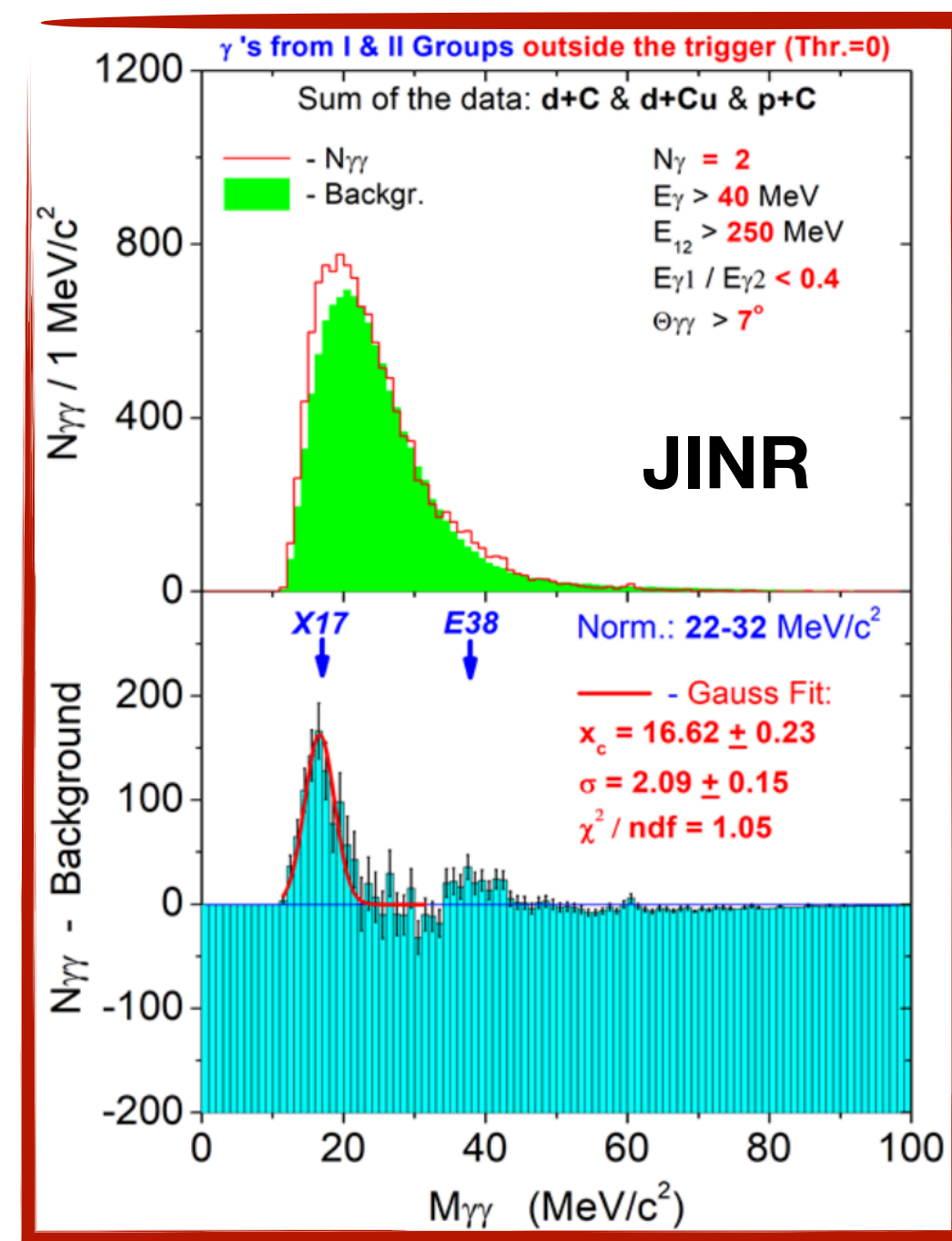
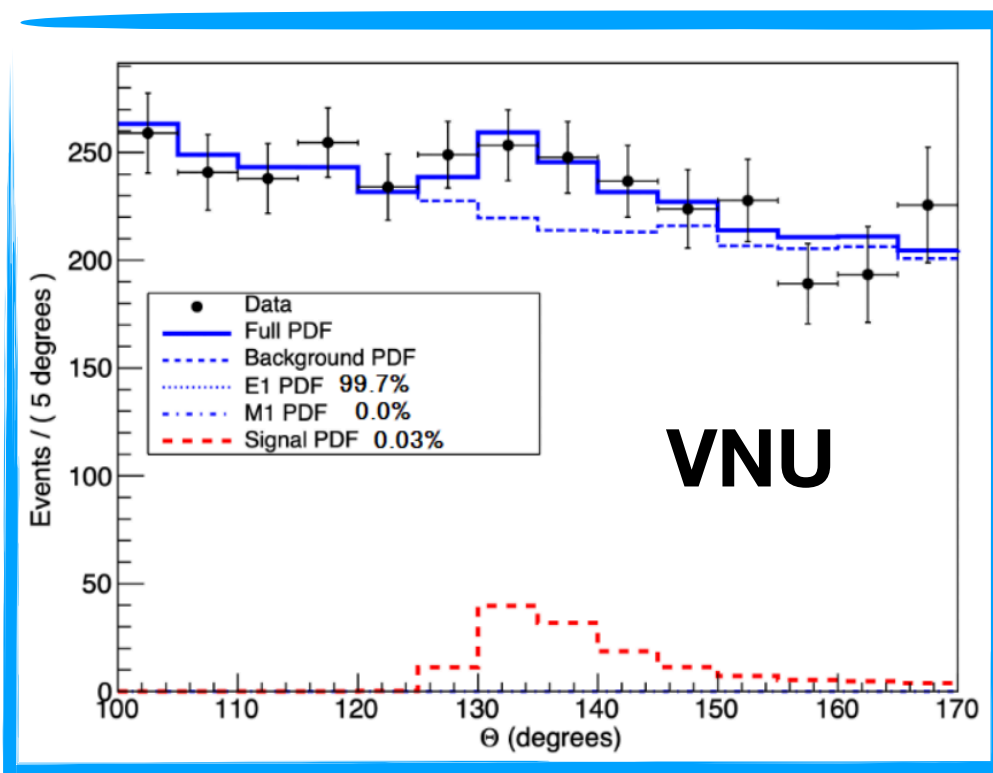
**MEGII at PSI**  
(arXiv:2411.07994): protons on a Li target, no significant signal



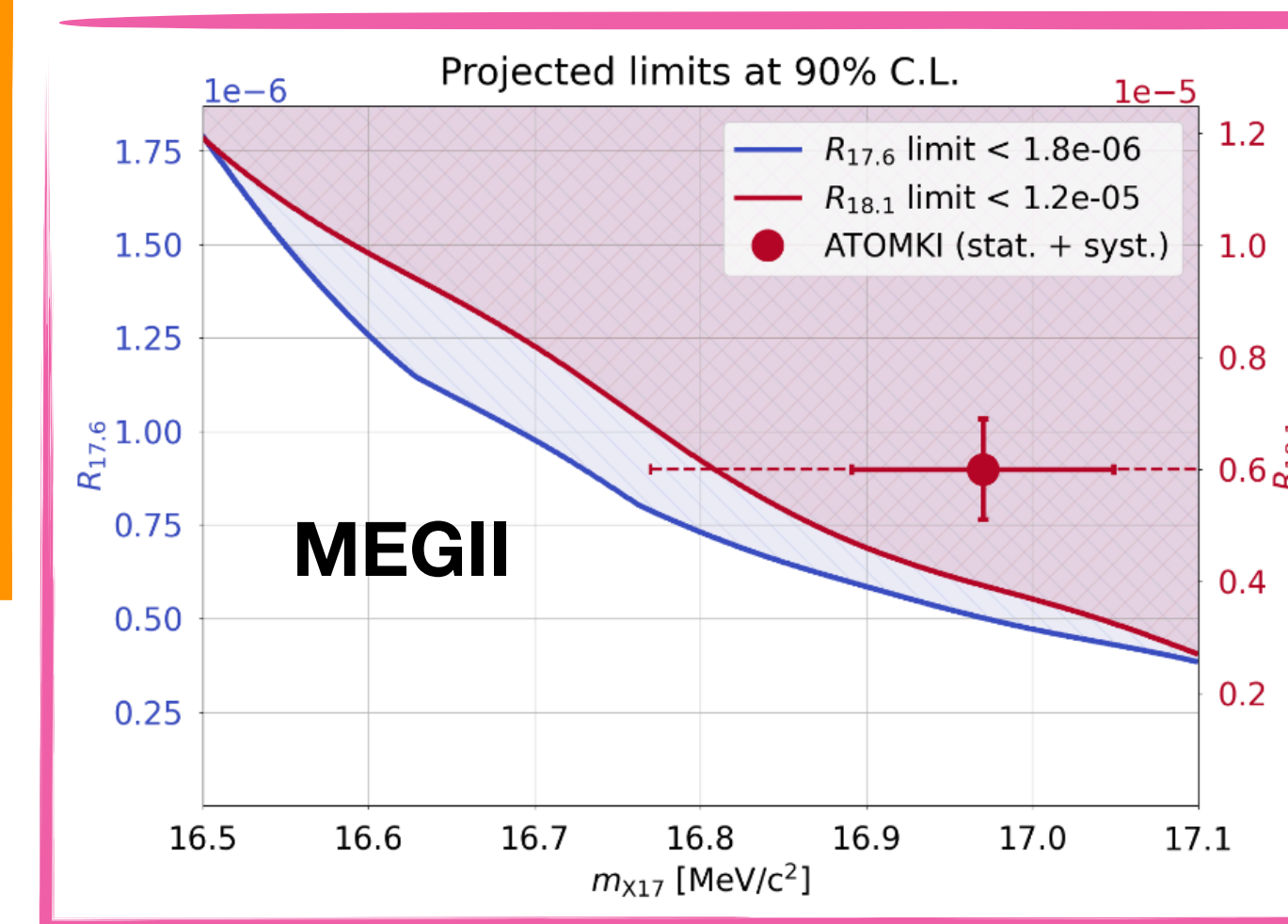
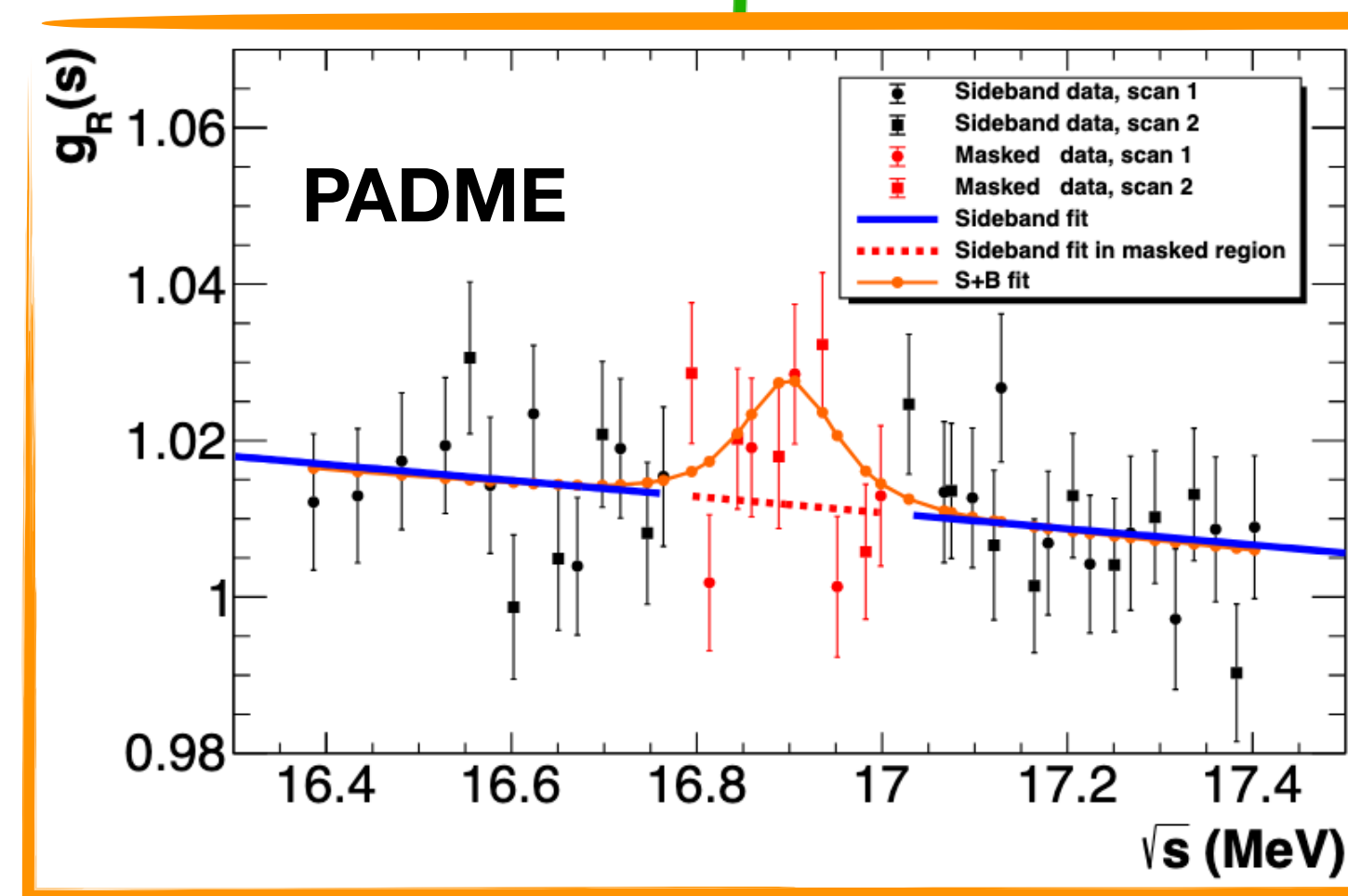
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## Positive Observations



## Negative Observations



More exploring to be done

# Experimental Anomalies: X17

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- Excess in  $e^+e^-$  invariant mass spectrum
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- Potential explanation: dark boson with a **protophobic** coupling to the SM

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

Kinetic mixing strength

Dark photon

SM QED current

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Make it more general

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

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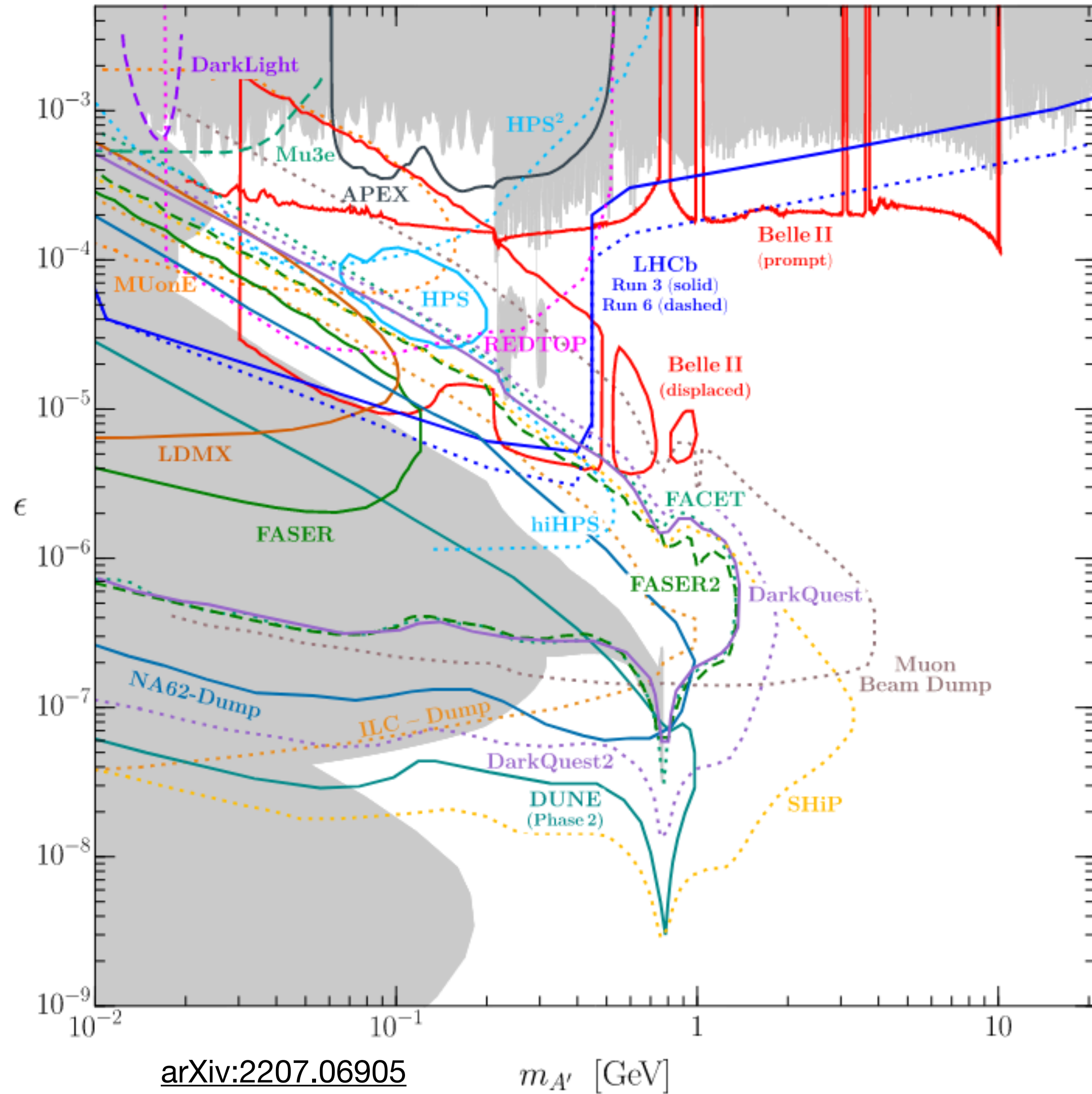
To fit with the magnitude of the excess observed from the ATOMKI  ${}^8\text{Be}$  experiment, and with existing limits:

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

⇒ “protophobic”

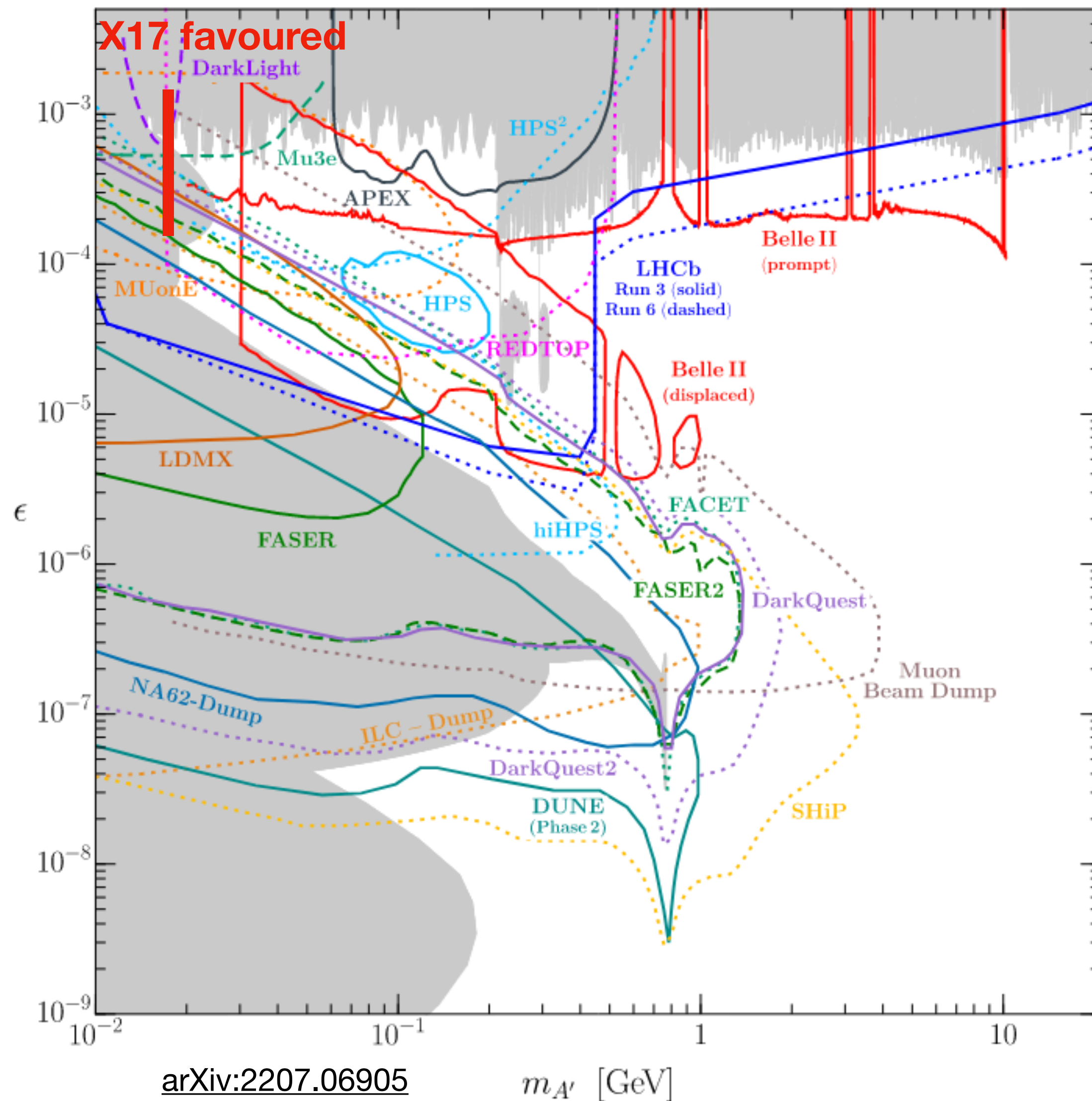
# Dark boson: current limits

Limits for past (grey) and future dark photon experiments



# Dark boson: current limits

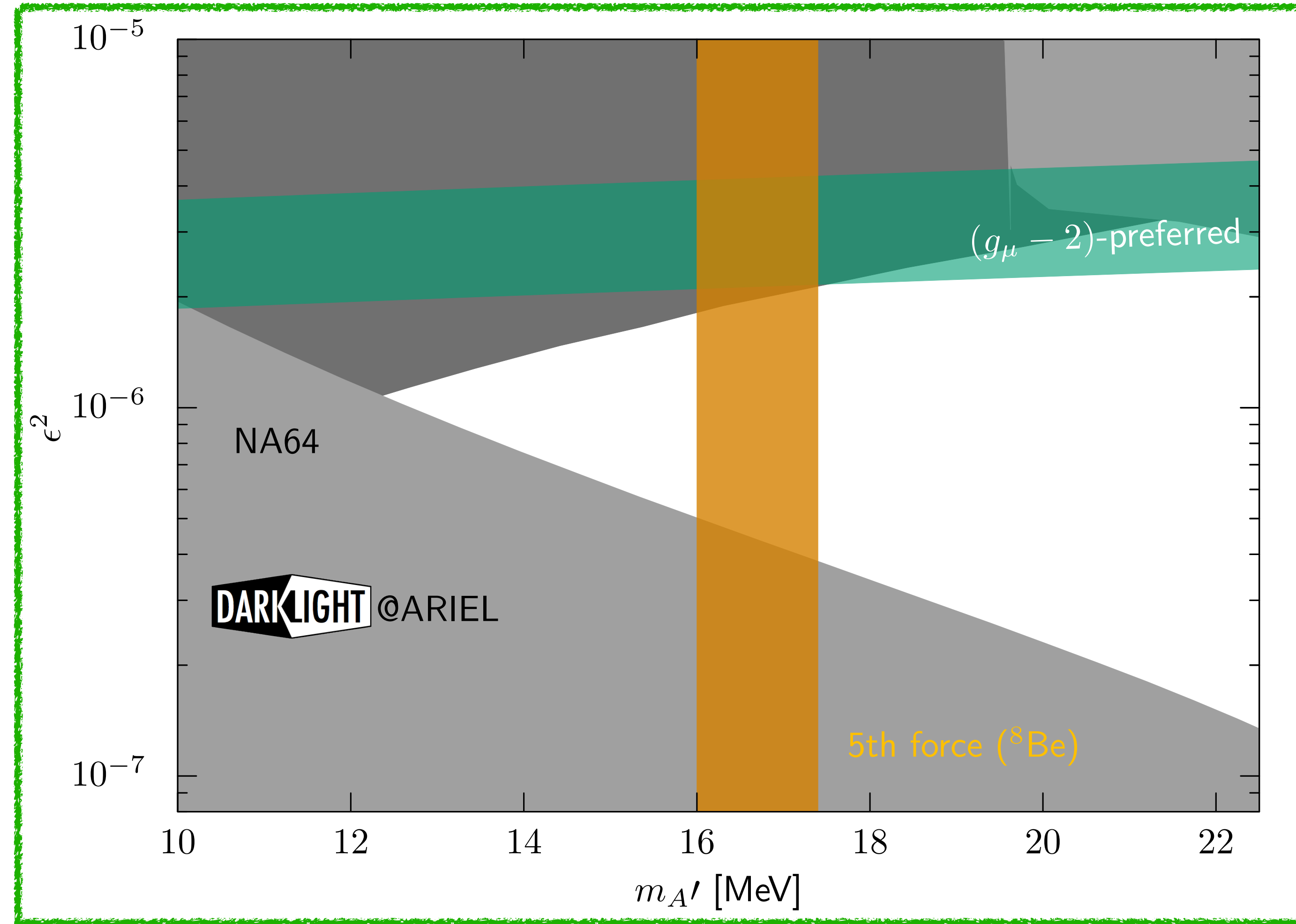
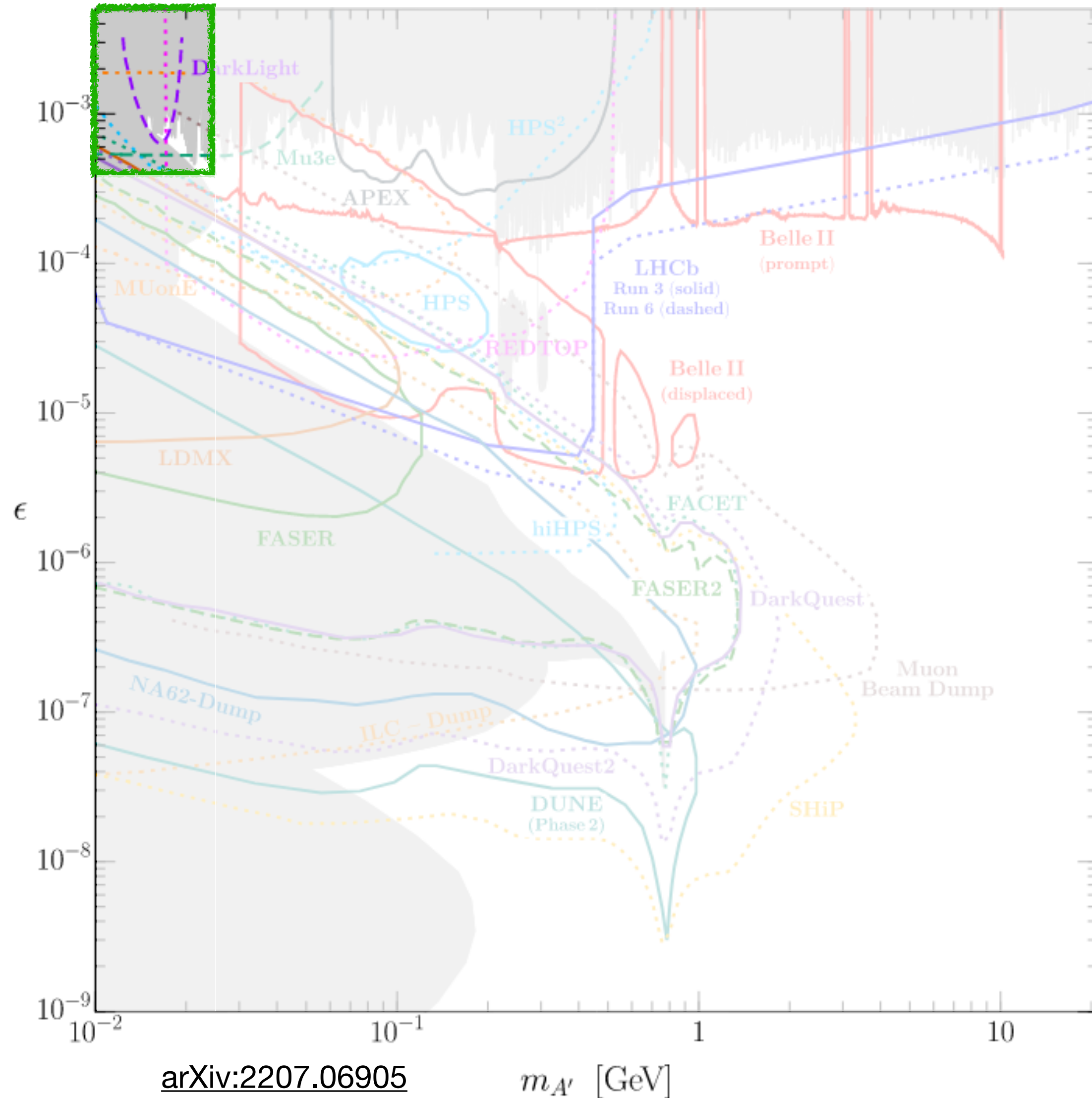
Limits for past (grey) and future dark photon experiments



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

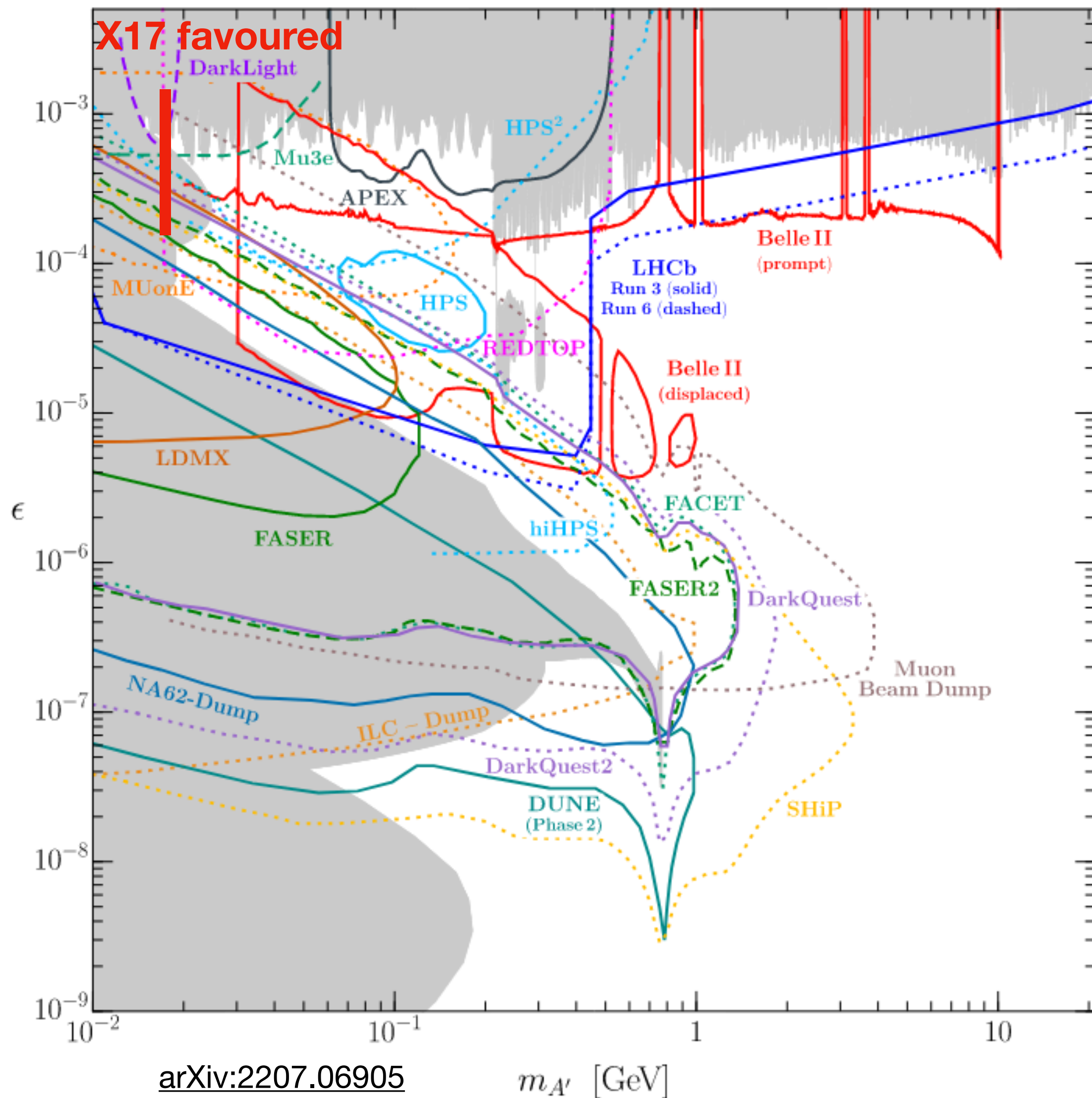
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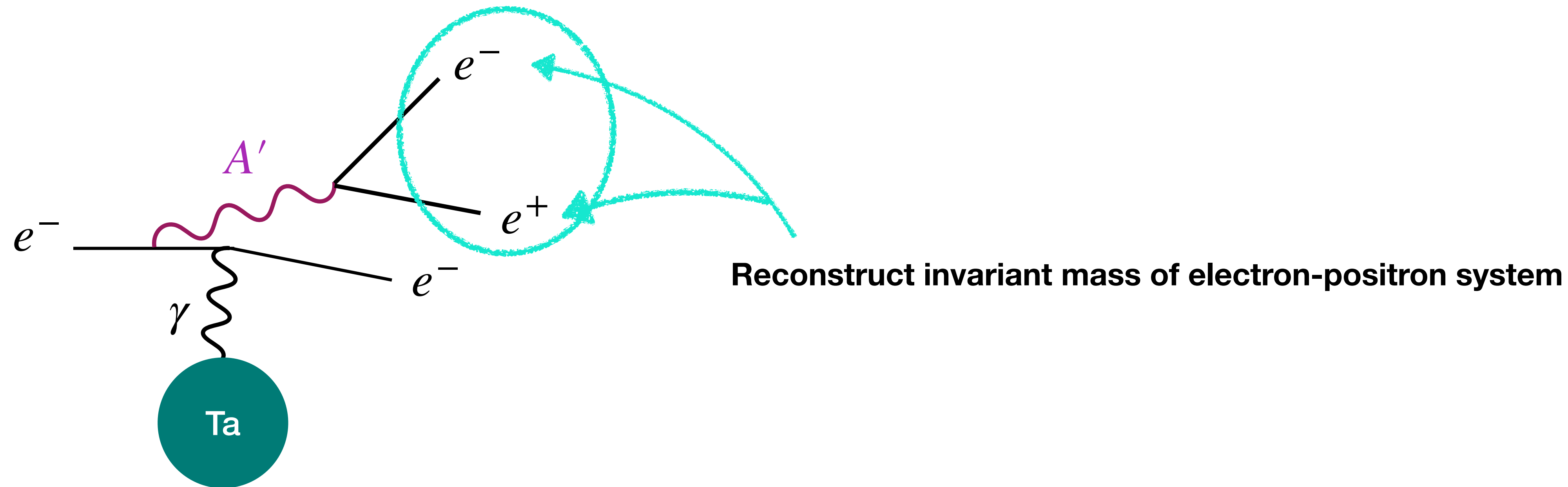


- Protophobic coupling means we have strayed from the standard dark photon model
- Can still show limits in same parameter space
- Main consequence of protophobic coupling: suppressed coupling to pions
- Reopens some previously excluded parameter space
- Can only be probed with a fully leptonic experiment



# DarkLight@ARIEL

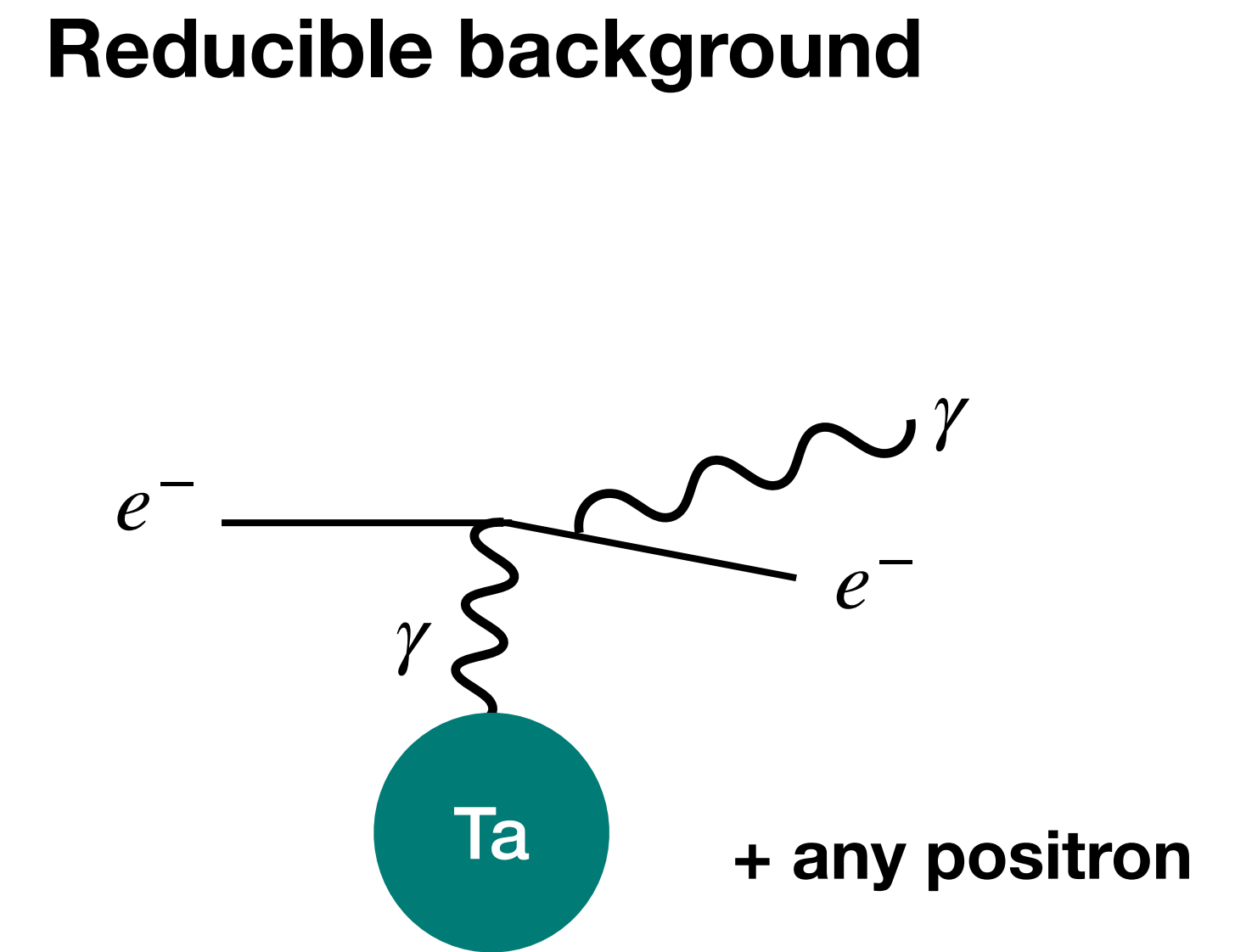
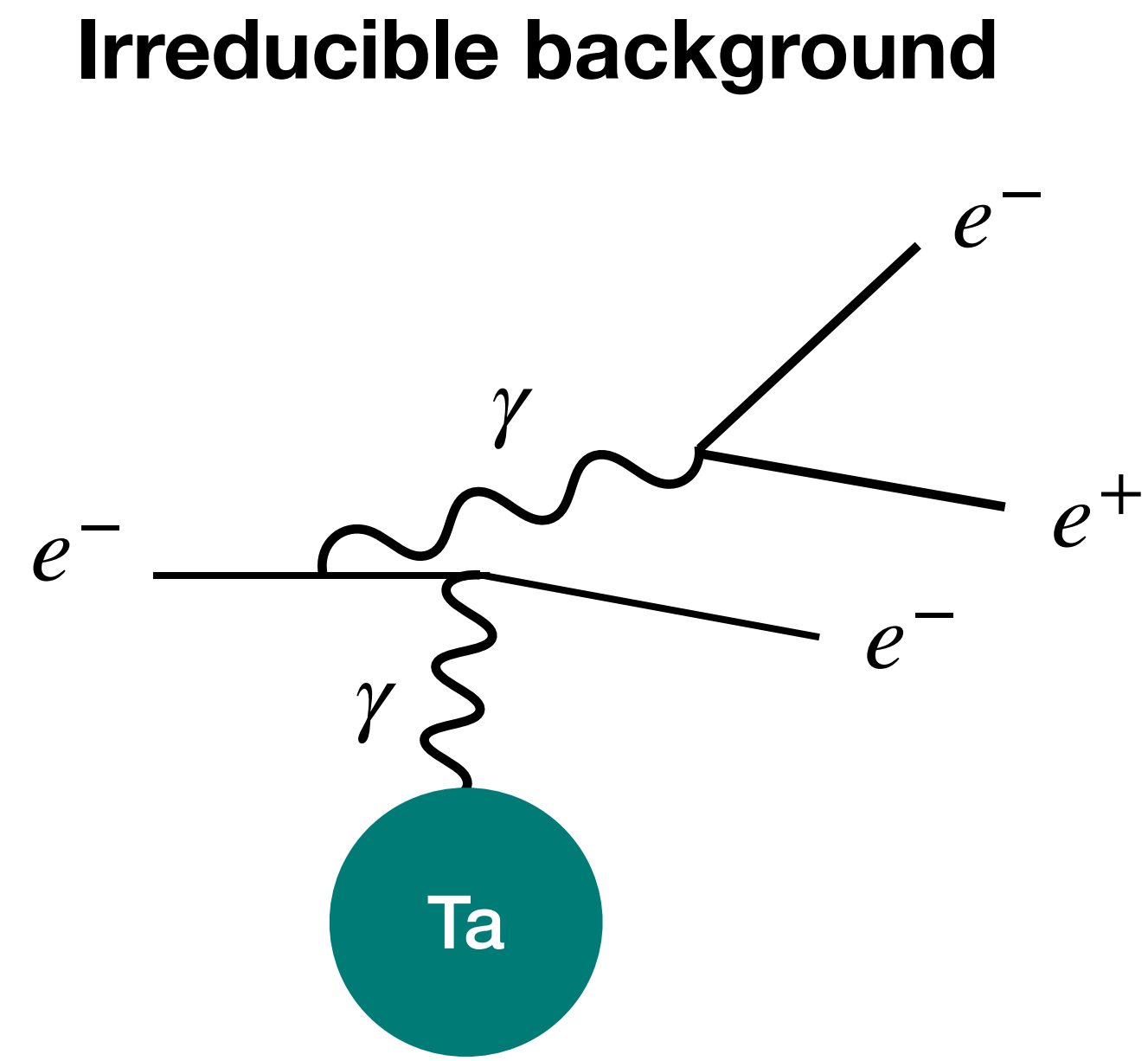
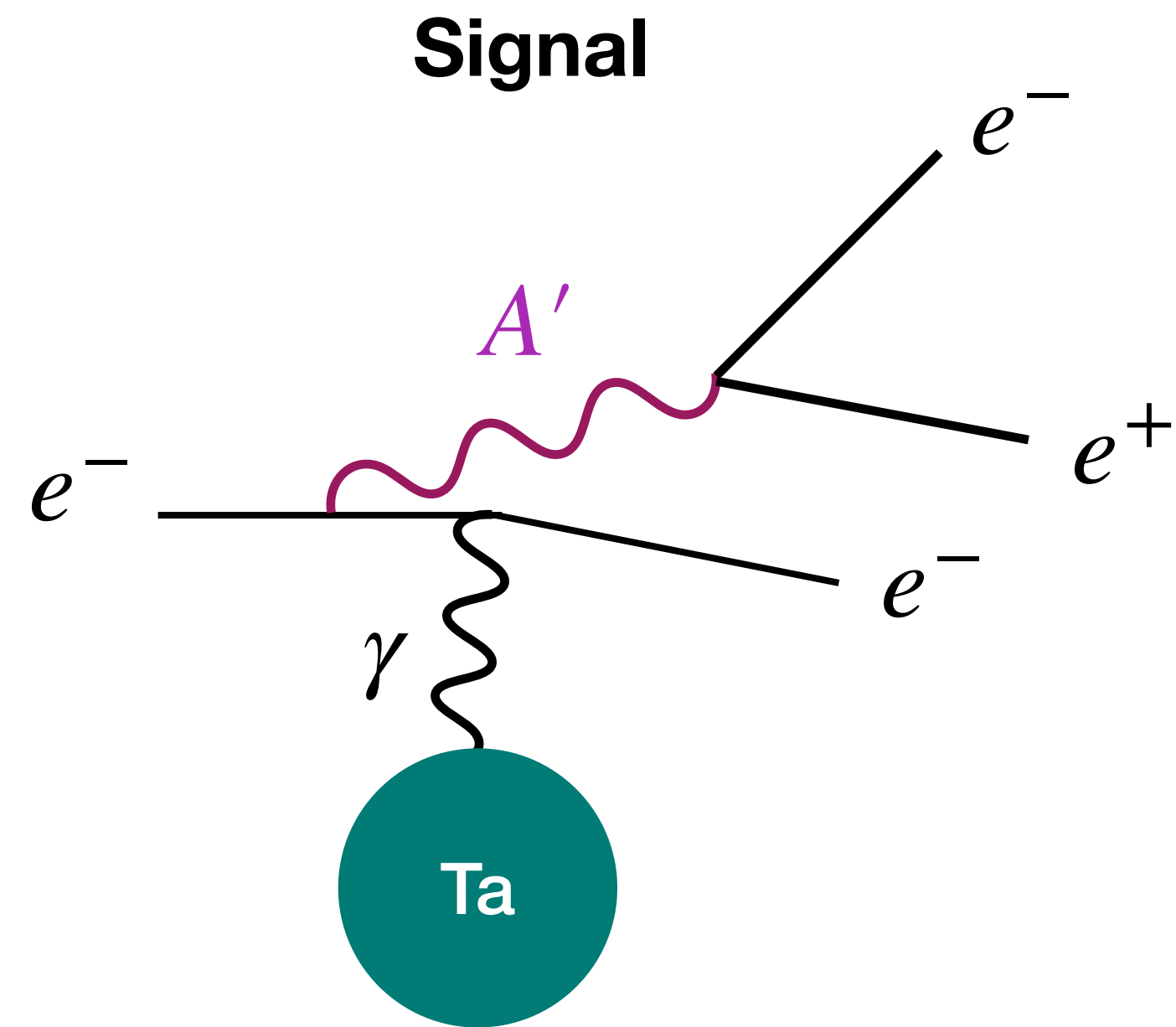
- Bombard fixed high Z target with low energy high intensity electron beam



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

# Signal and background

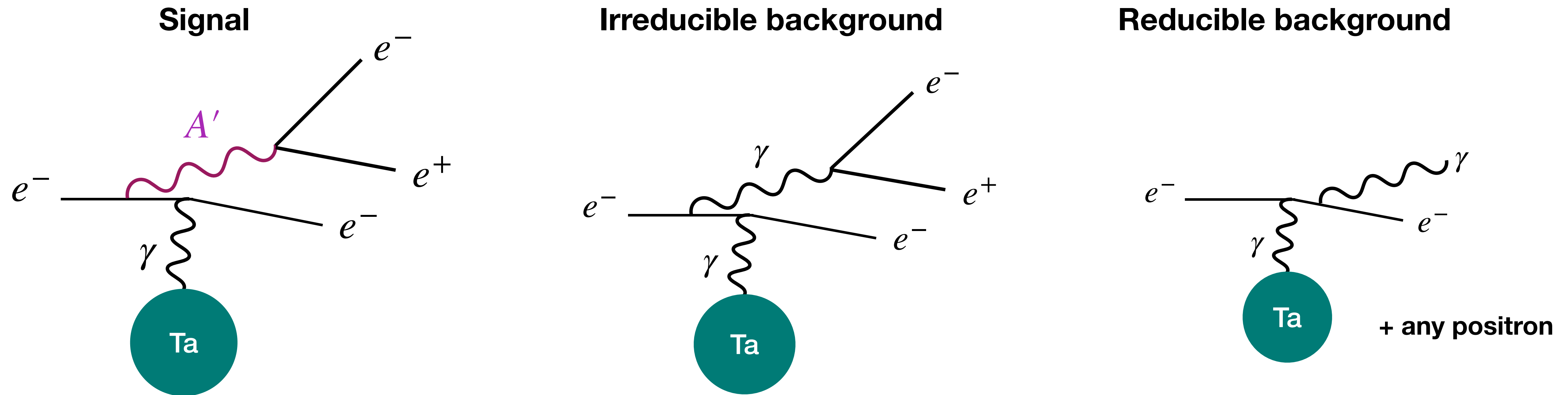
- Two main background processes to consider:



# Signal and background

- Two main background processes to consider:

10



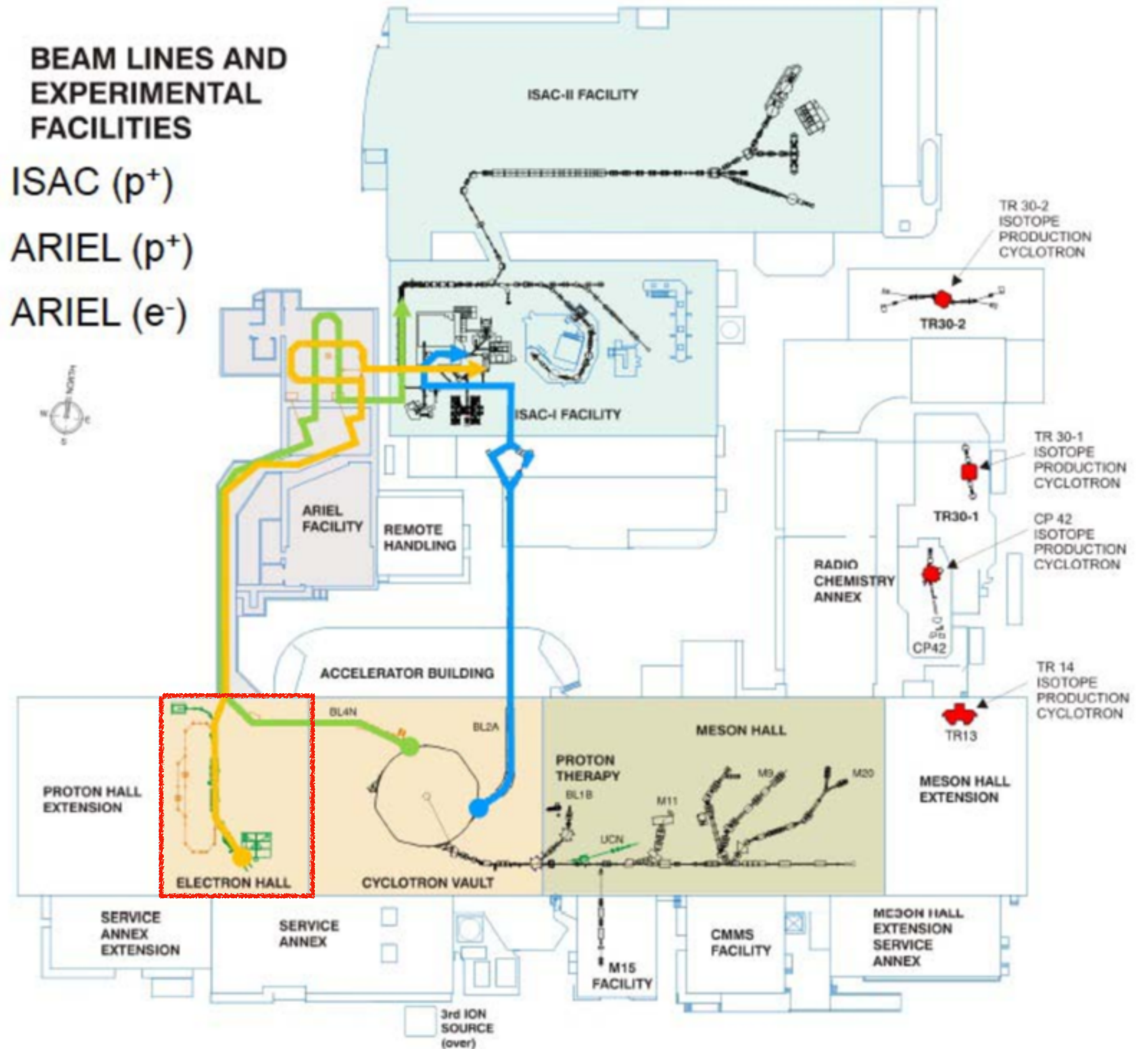
- Carefully select electron and positron momenta using the spectrometer magnets and arm angles to maximize signal
- Put very strict coincidence condition on the trigger

# ARIEL

- Advanced Rare Isotope Laboratory
- New facility to be operational in 2027

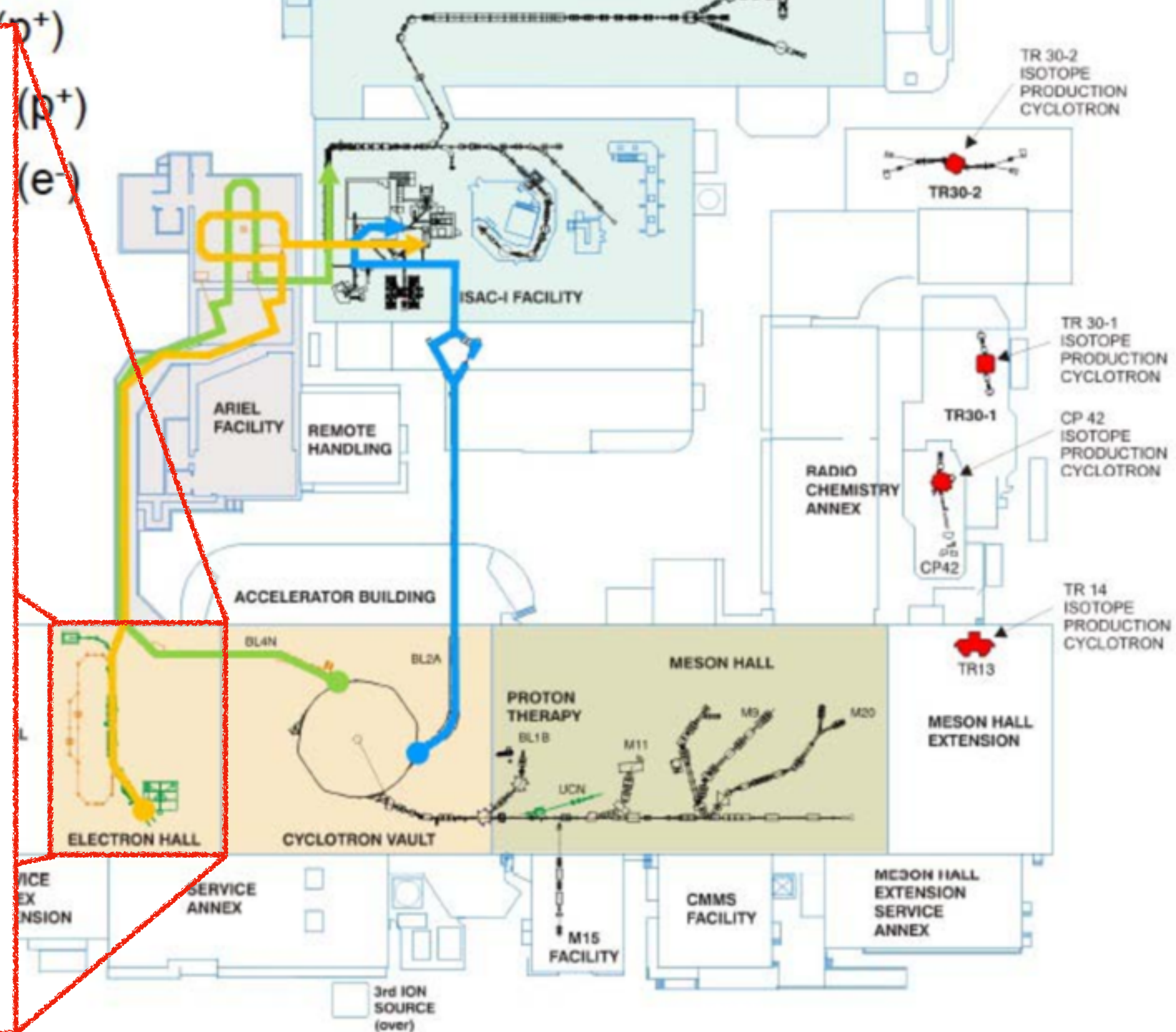
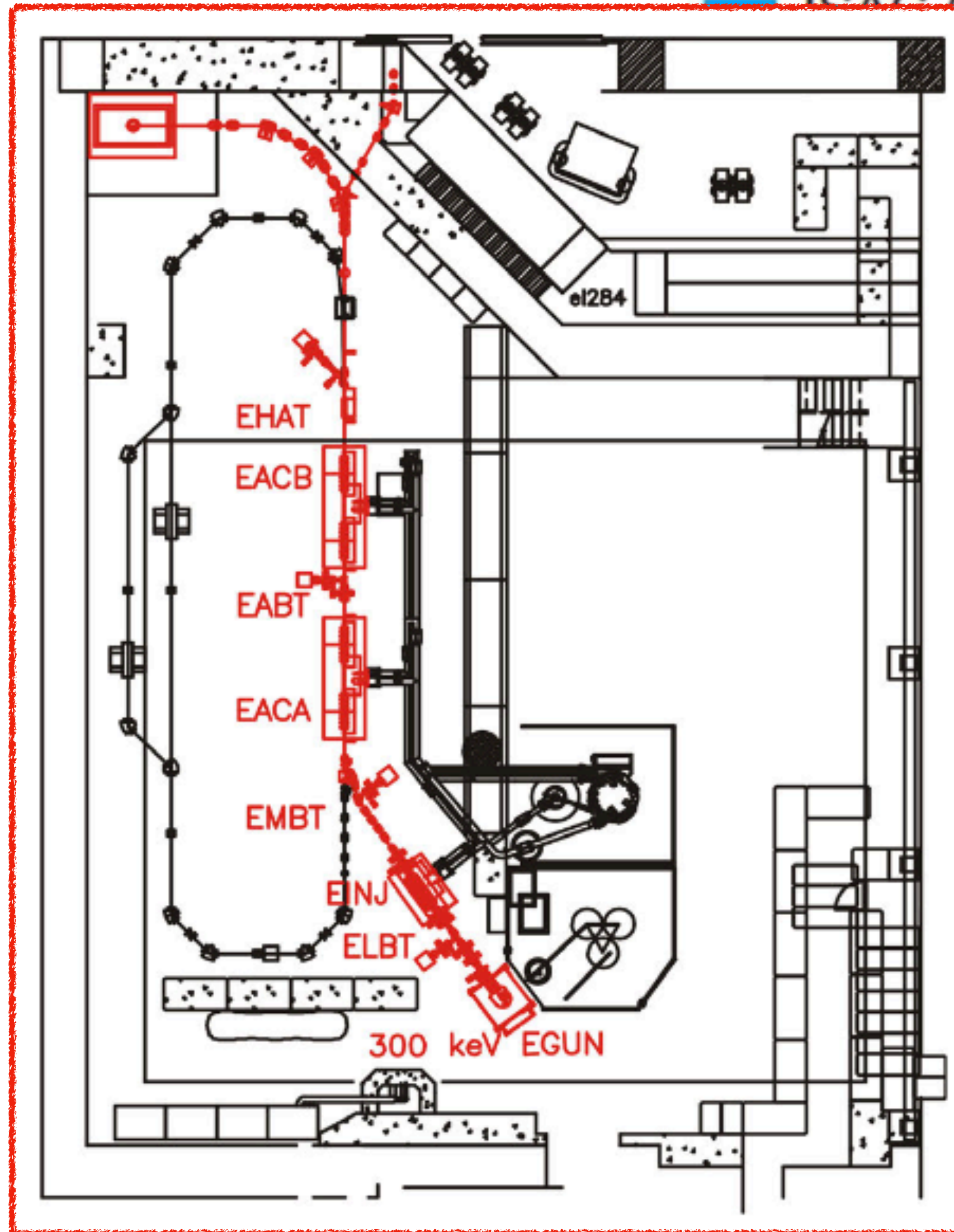
## BEAM LINES AND EXPERIMENTAL FACILITIES

- ISAC ( $p^+$ )
- ARIEL ( $p^+$ )
- ARIEL ( $e^-$ )



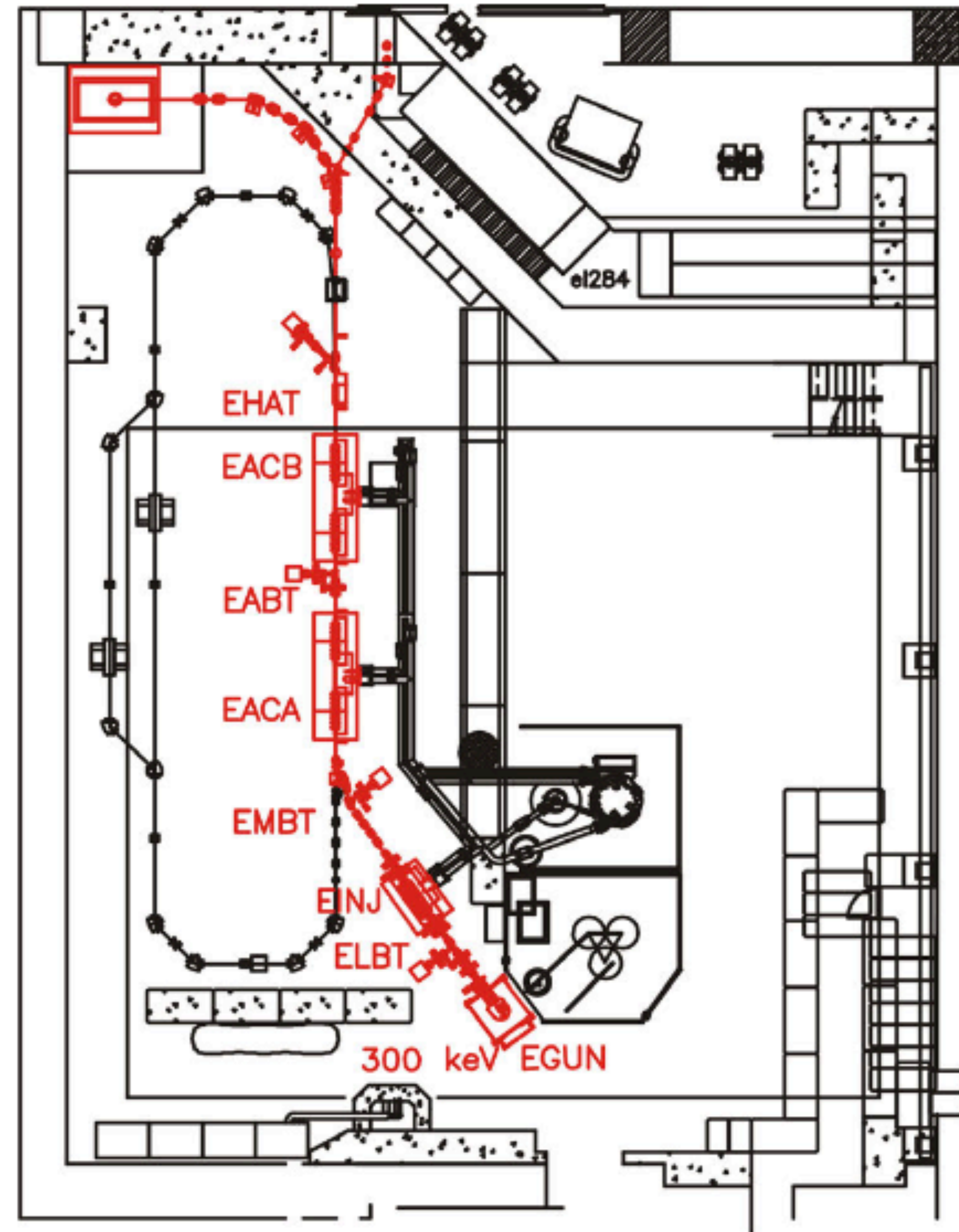
# ARIEL

## BEAM LINES AND EXPERIMENTAL FACILITIES



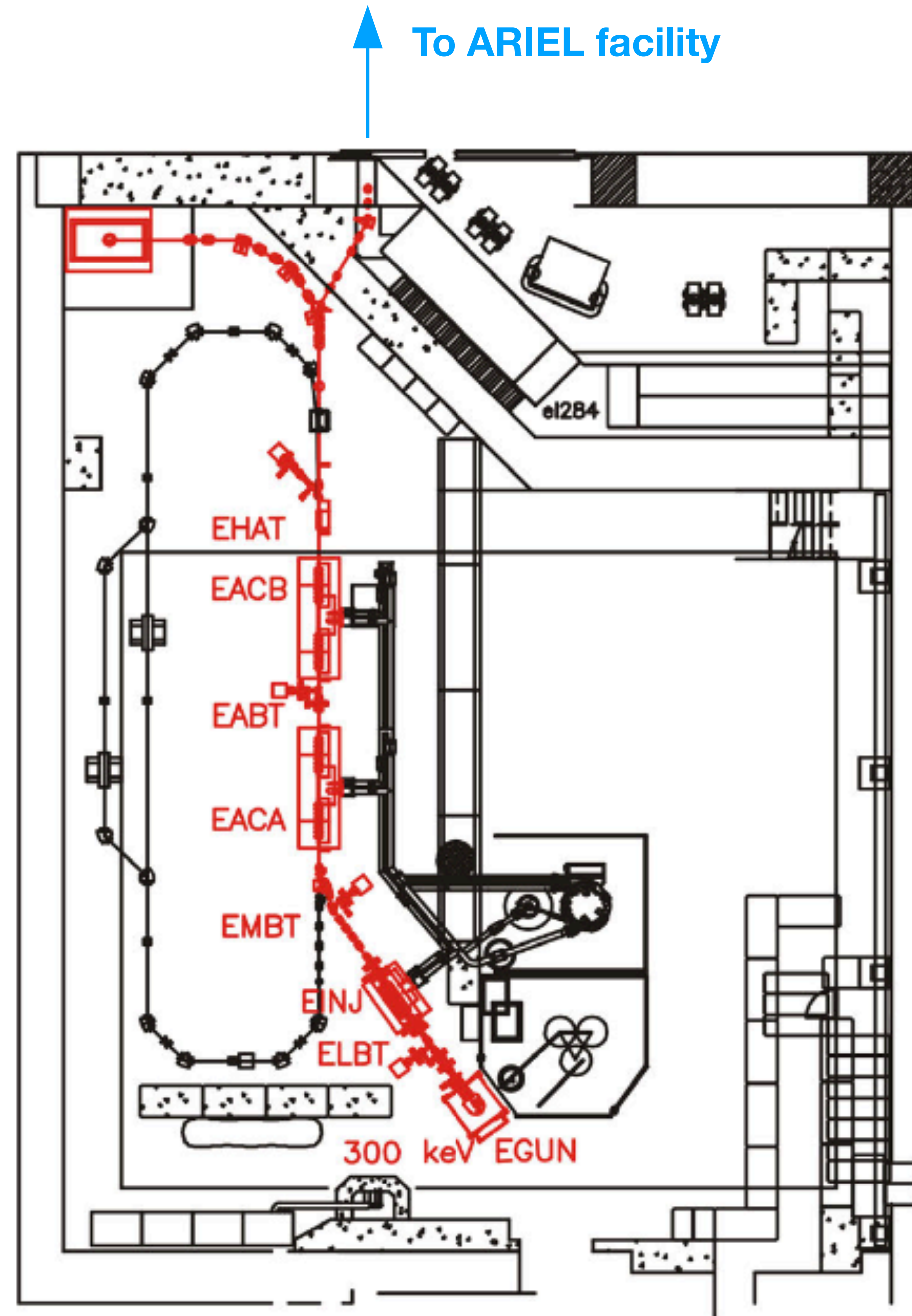
# ARIEL e-linac

- 30 MeV electron beam setup



# ARIEL e-linac

- 30 MeV electron beam setup

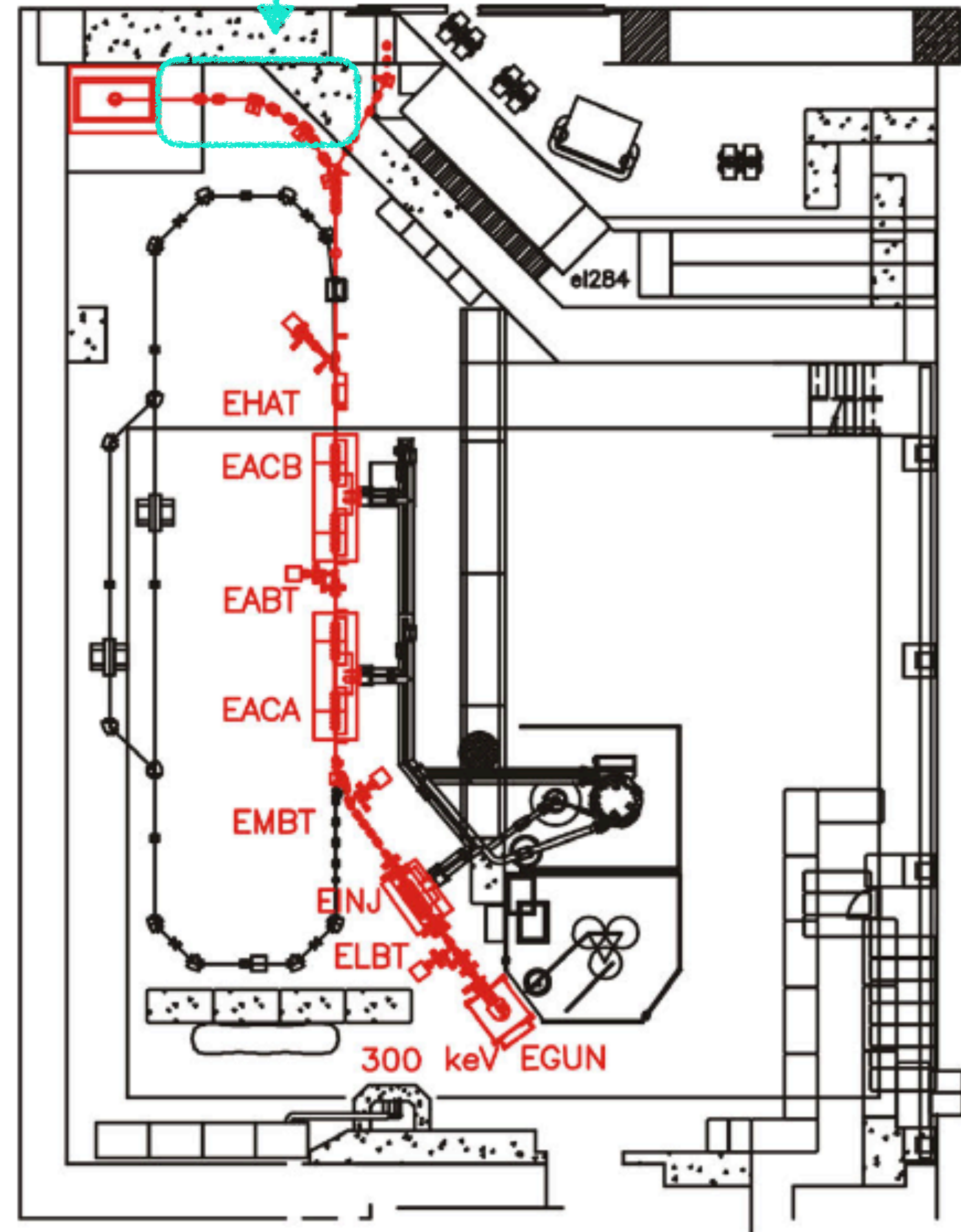


# ARIEL e-linac

- 30 MeV electron beam setup

**DARKLIGHT**

↑ To ARIEL facility

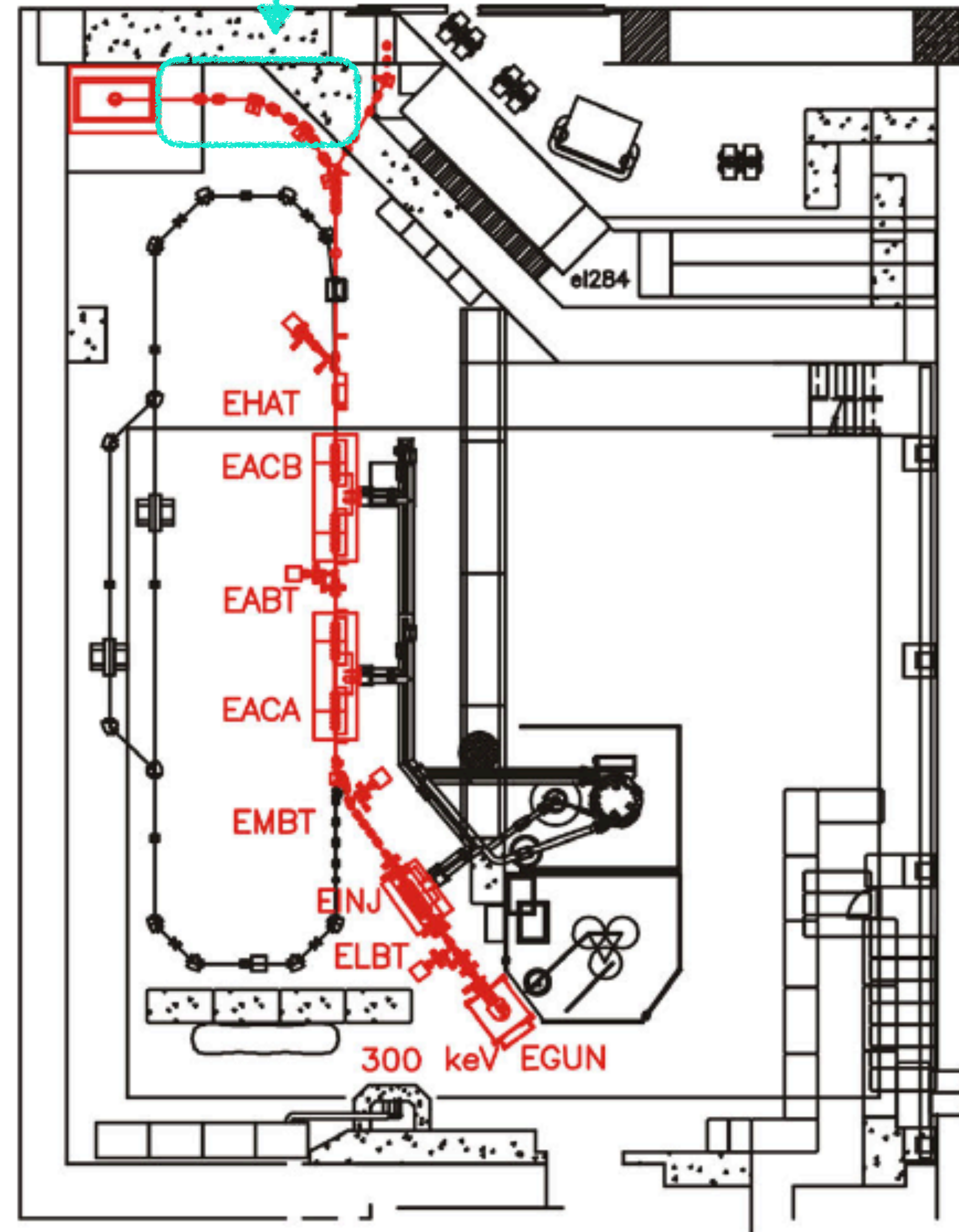


# ARIEL e-linac

DARKLIGHT

To ARIEL facility

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

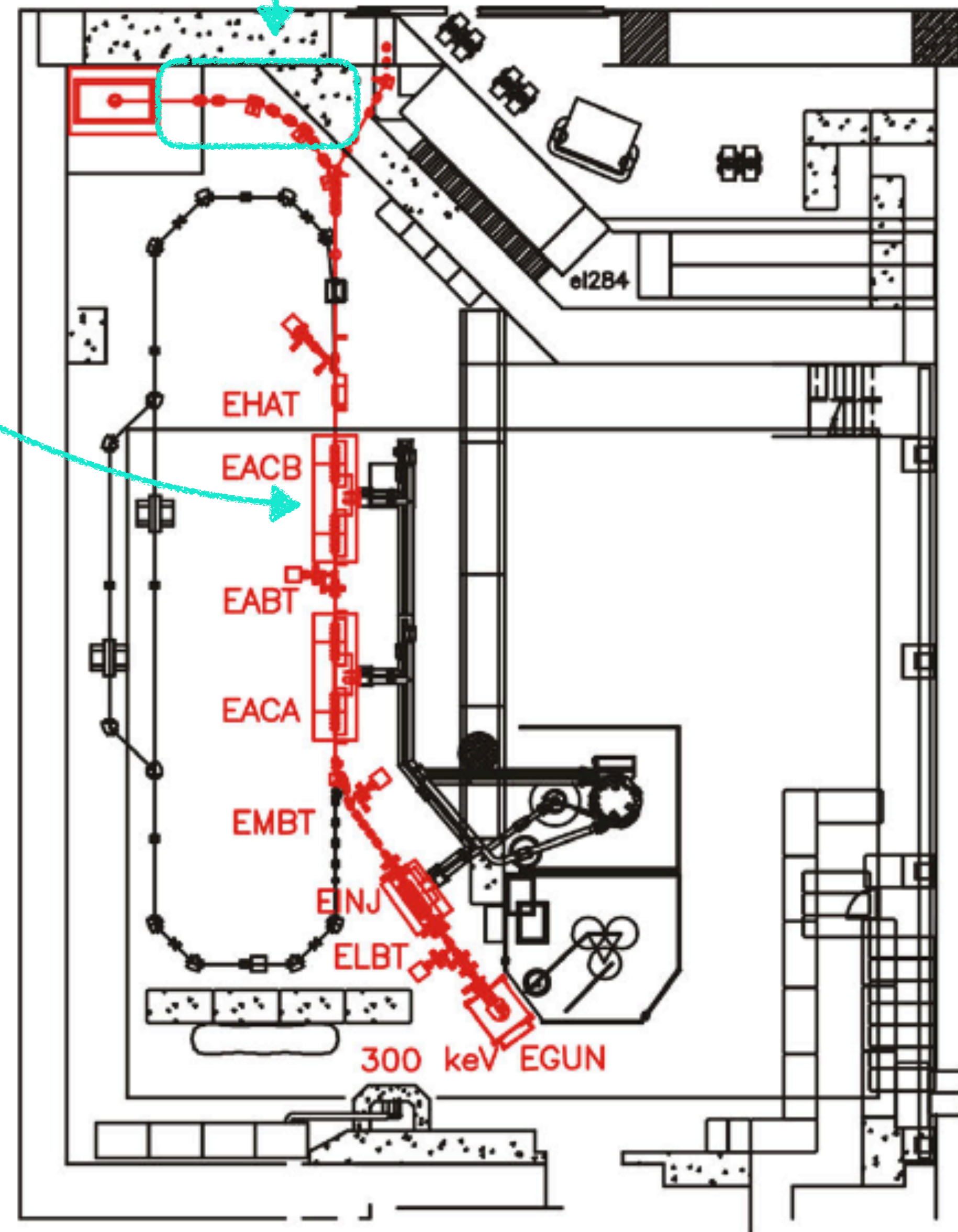


# ARIEL e-linac

DARKLIGHT

To ARIEL facility

- 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

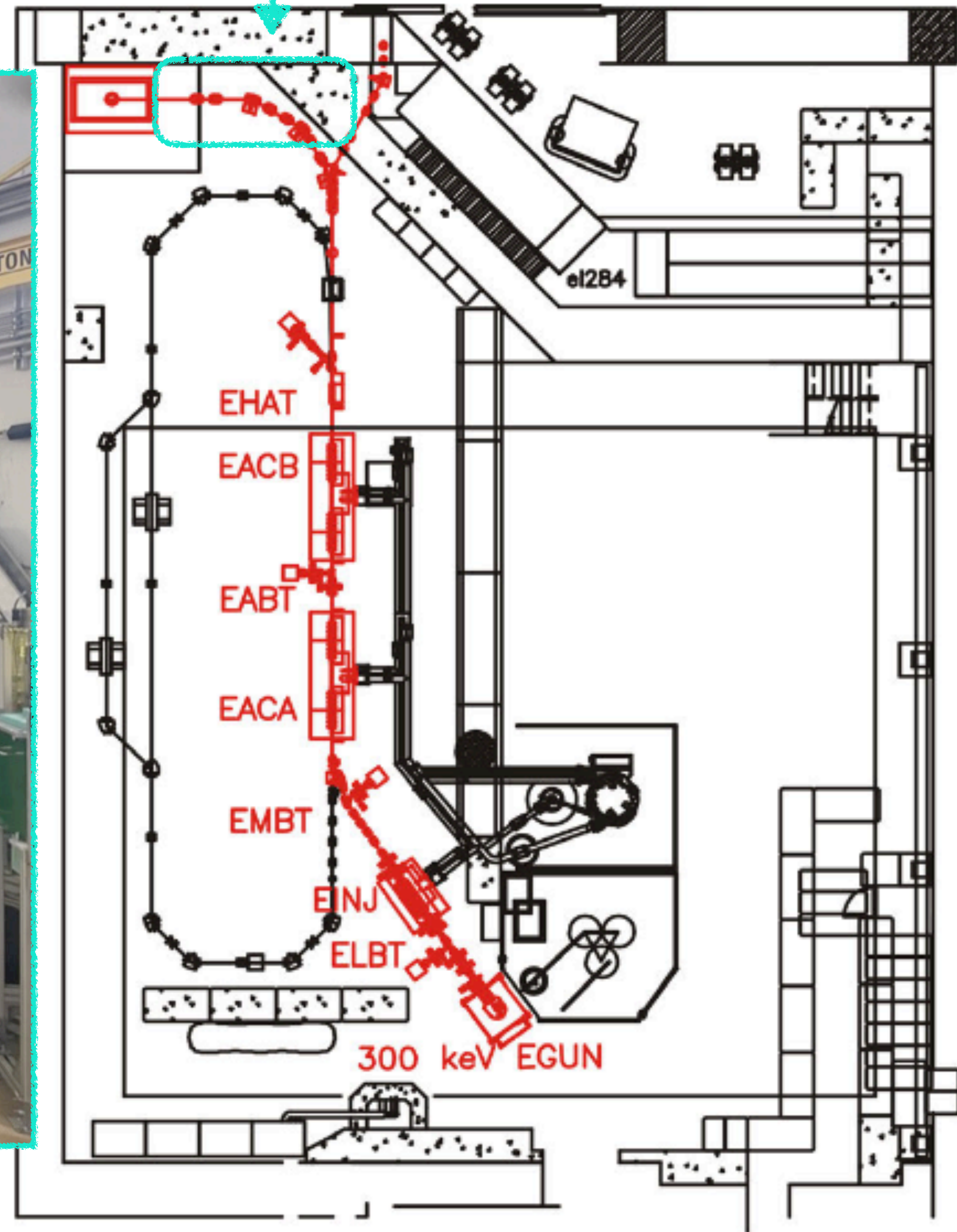


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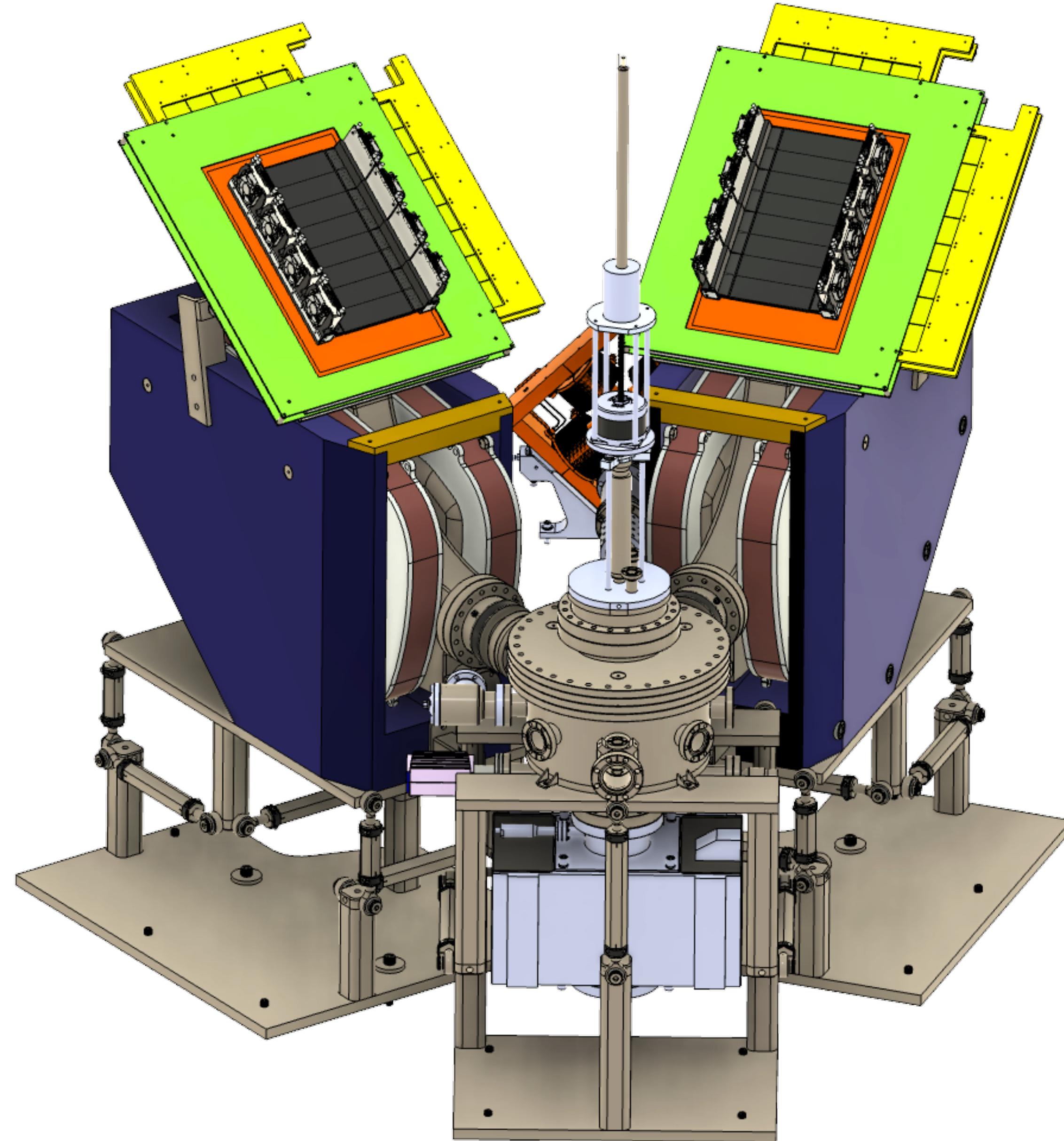
**DARKLIGHT**

↑ To ARIEL facility

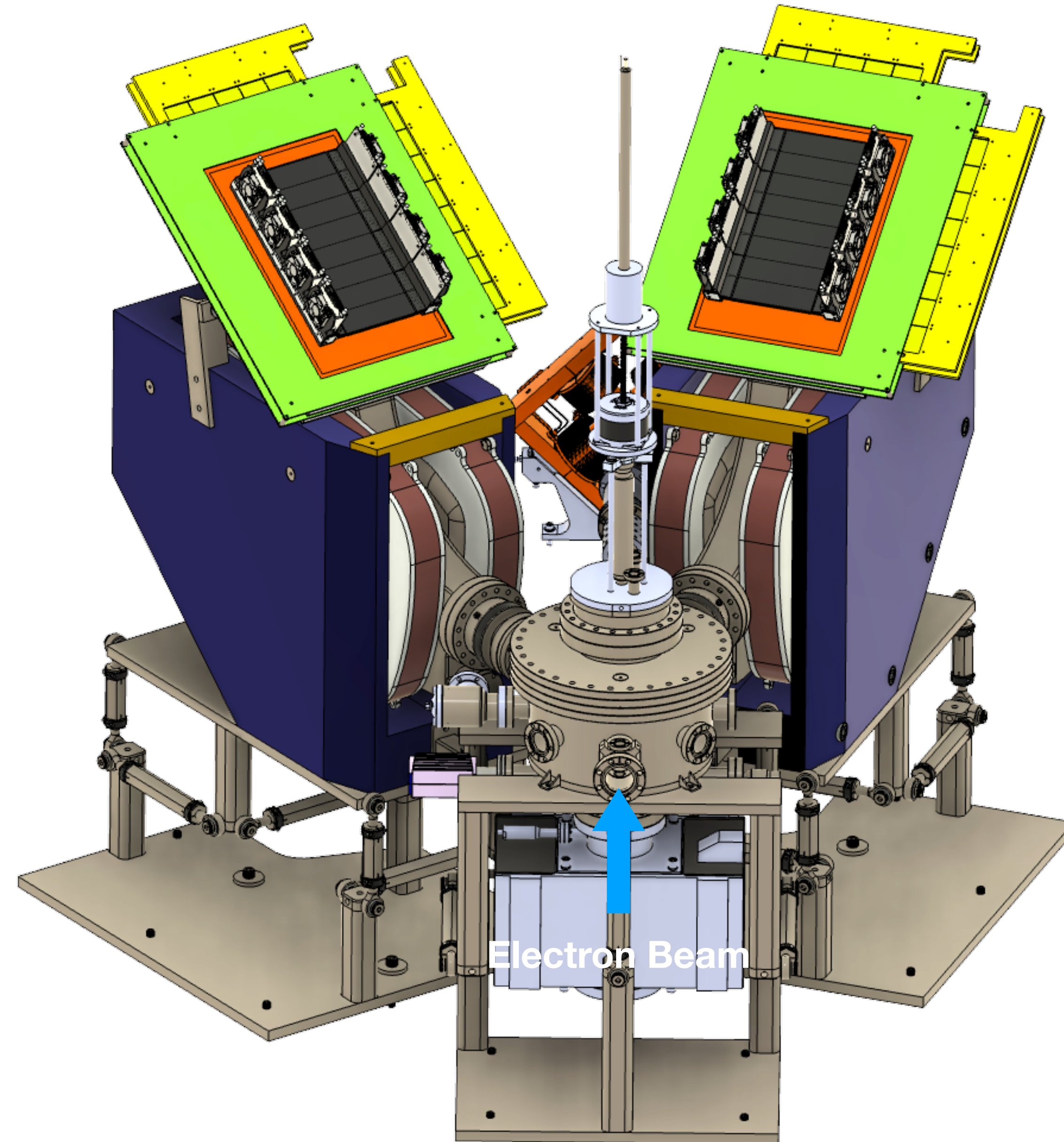
Pre May 2025



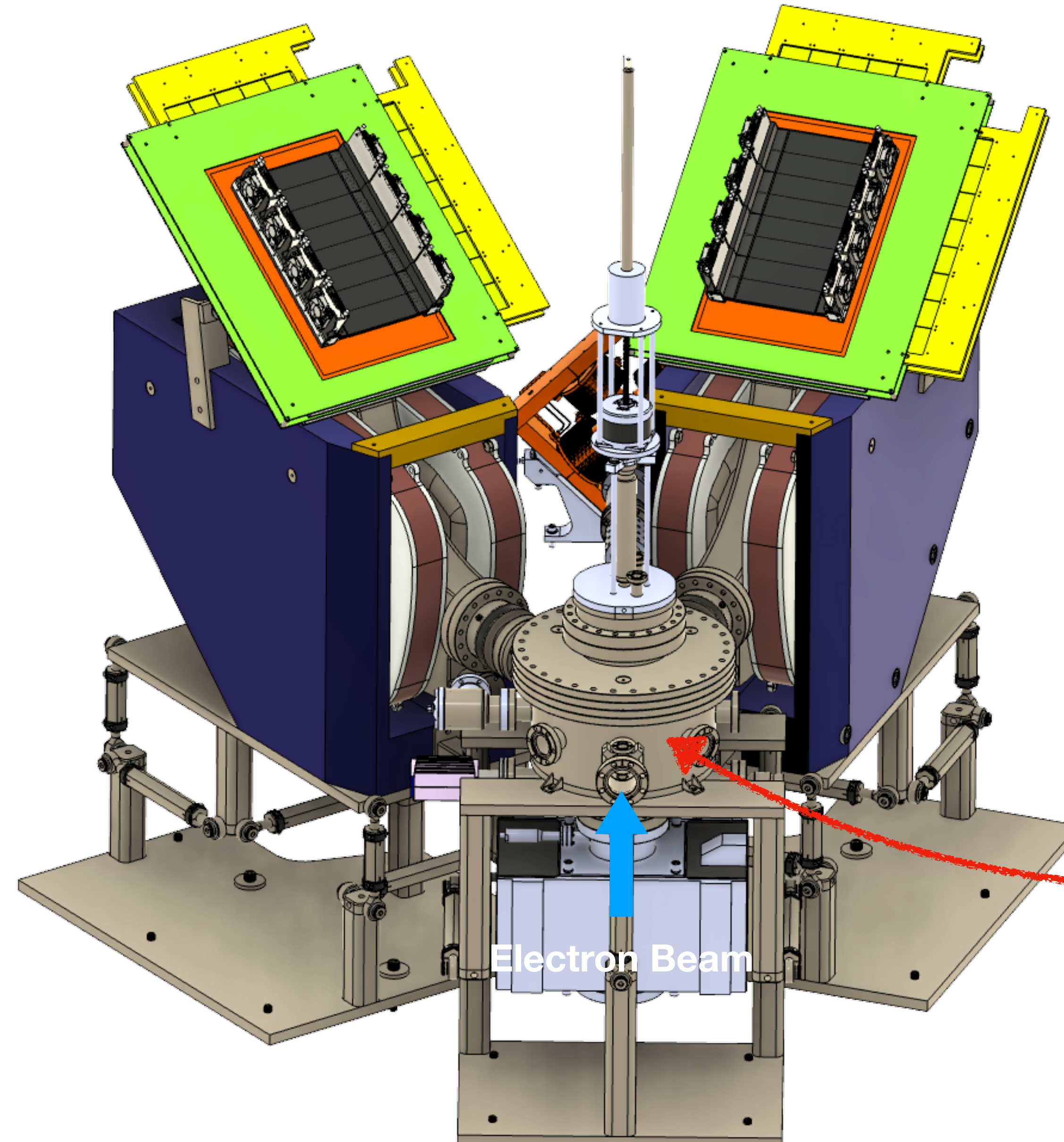
# DarkLight apparatus



# DarkLight apparatus



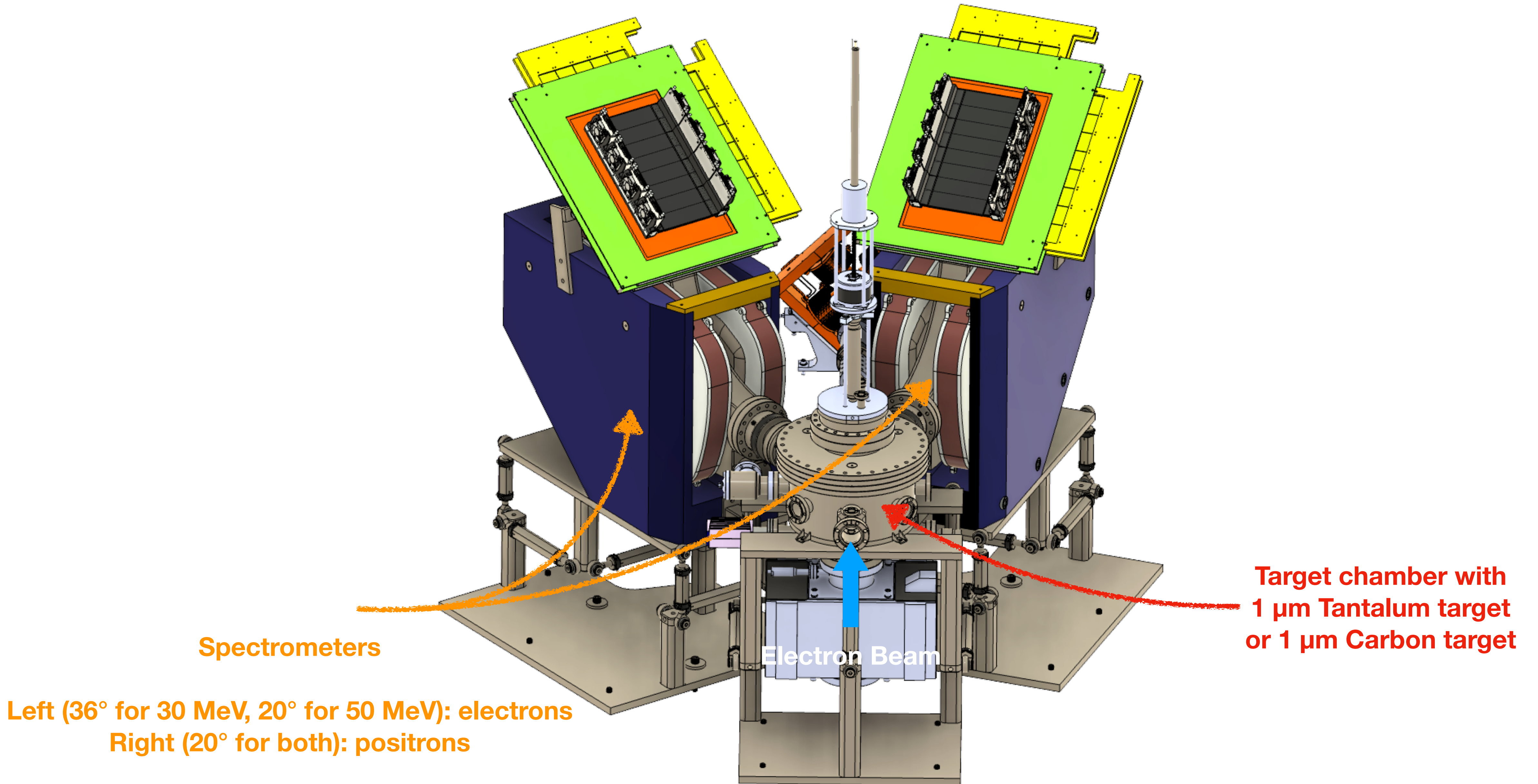
# DarkLight apparatus



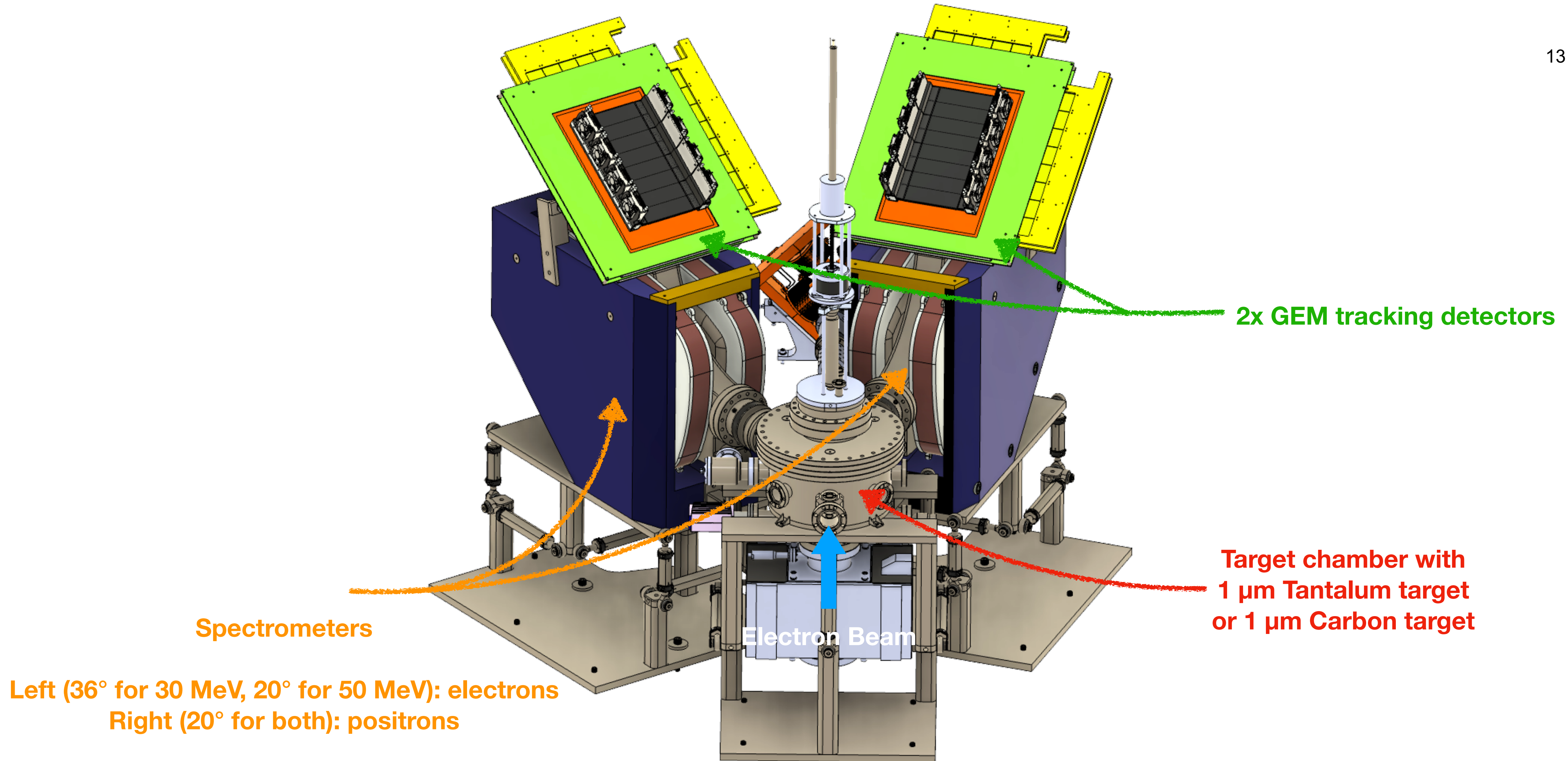
Electron Beam

Target chamber with  
1  $\mu\text{m}$  Tantalum target  
or 1  $\mu\text{m}$  Carbon target

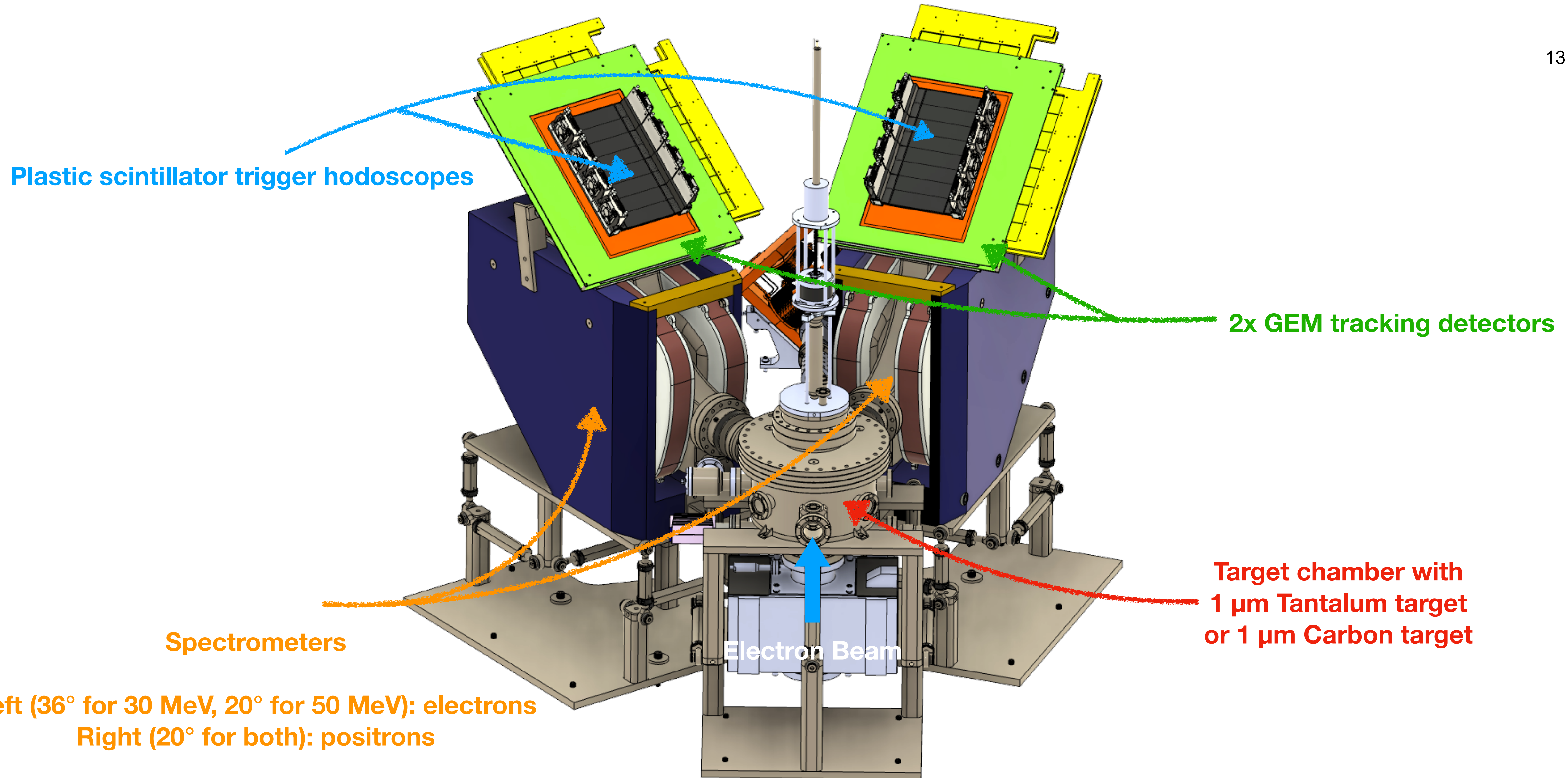
# DarkLight apparatus



# DarkLight apparatus



# DarkLight apparatus

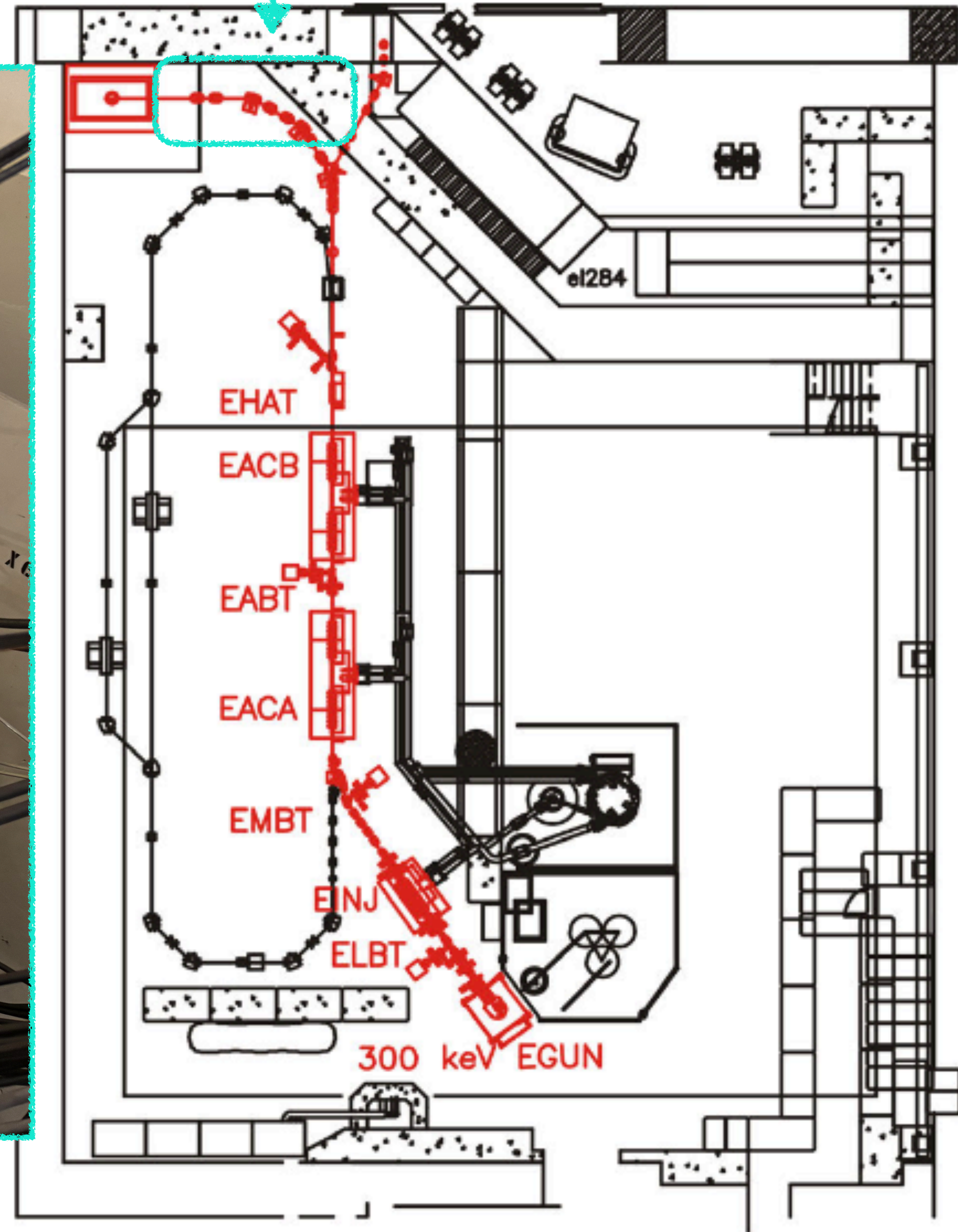
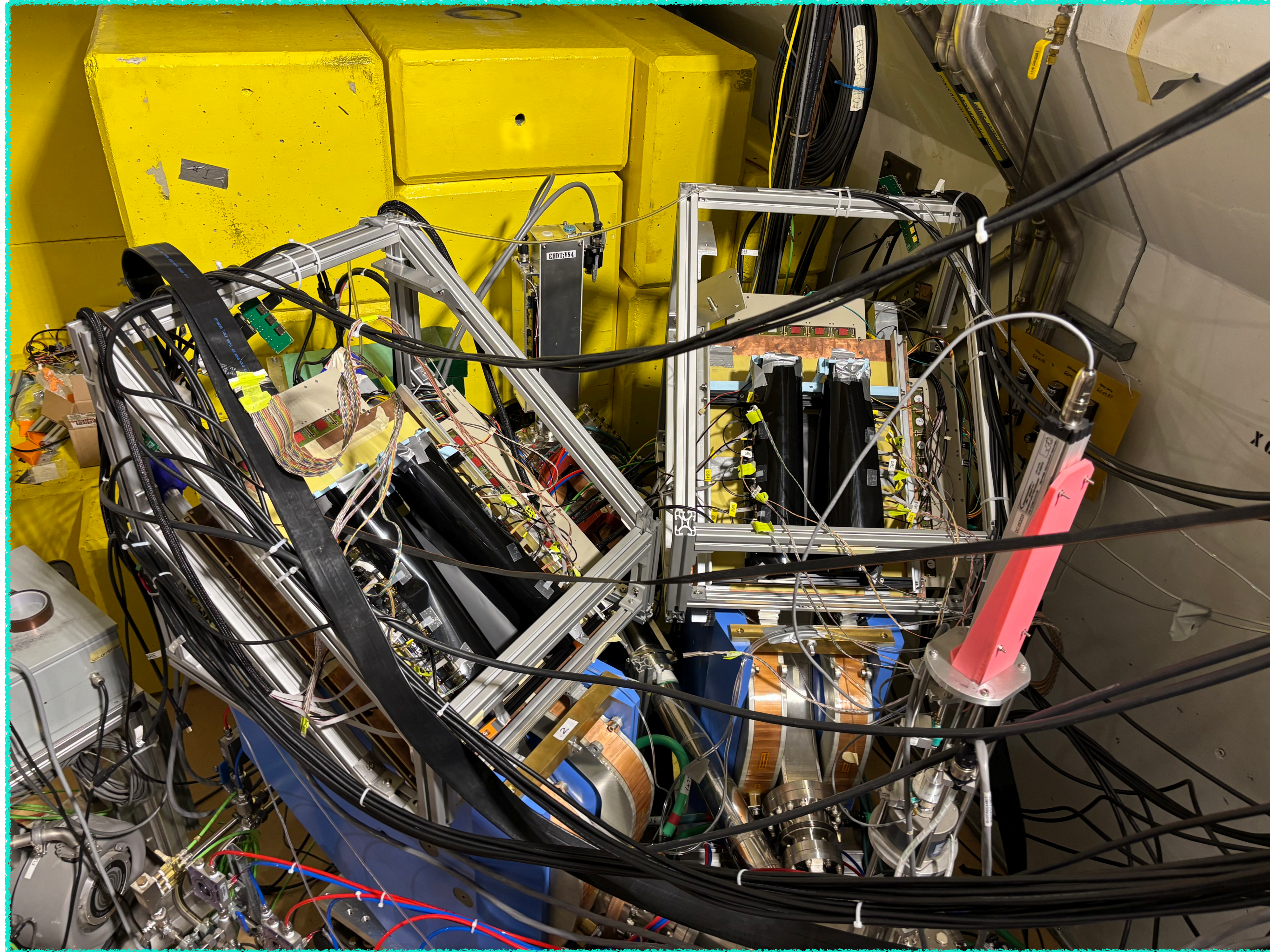


# ARIEL e-linac



Post July 2025

To ARIEL facility



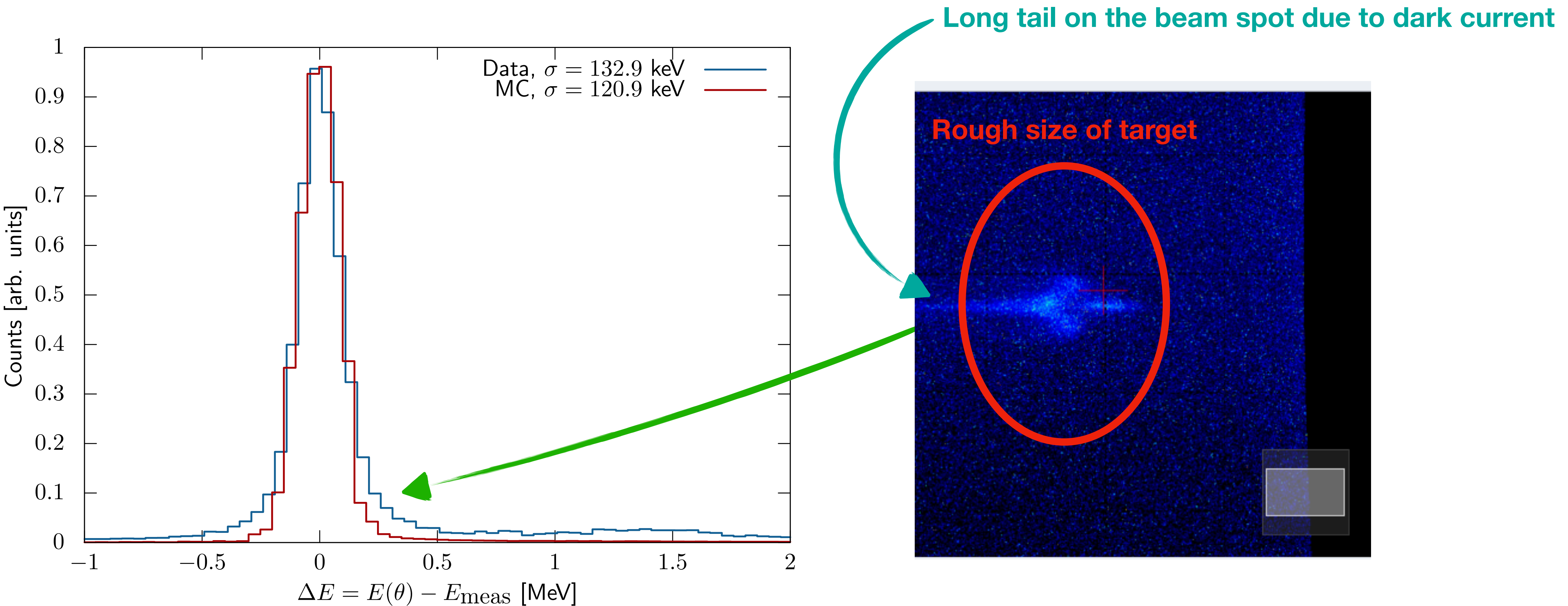
# Commissioning: Early 2026

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	

# Commissioning: Early 2026

- eLinac beam less well-understood than expected
  - Resulted in dark current scattering through the target ladder frame
- GEMs are performing sub-optimally

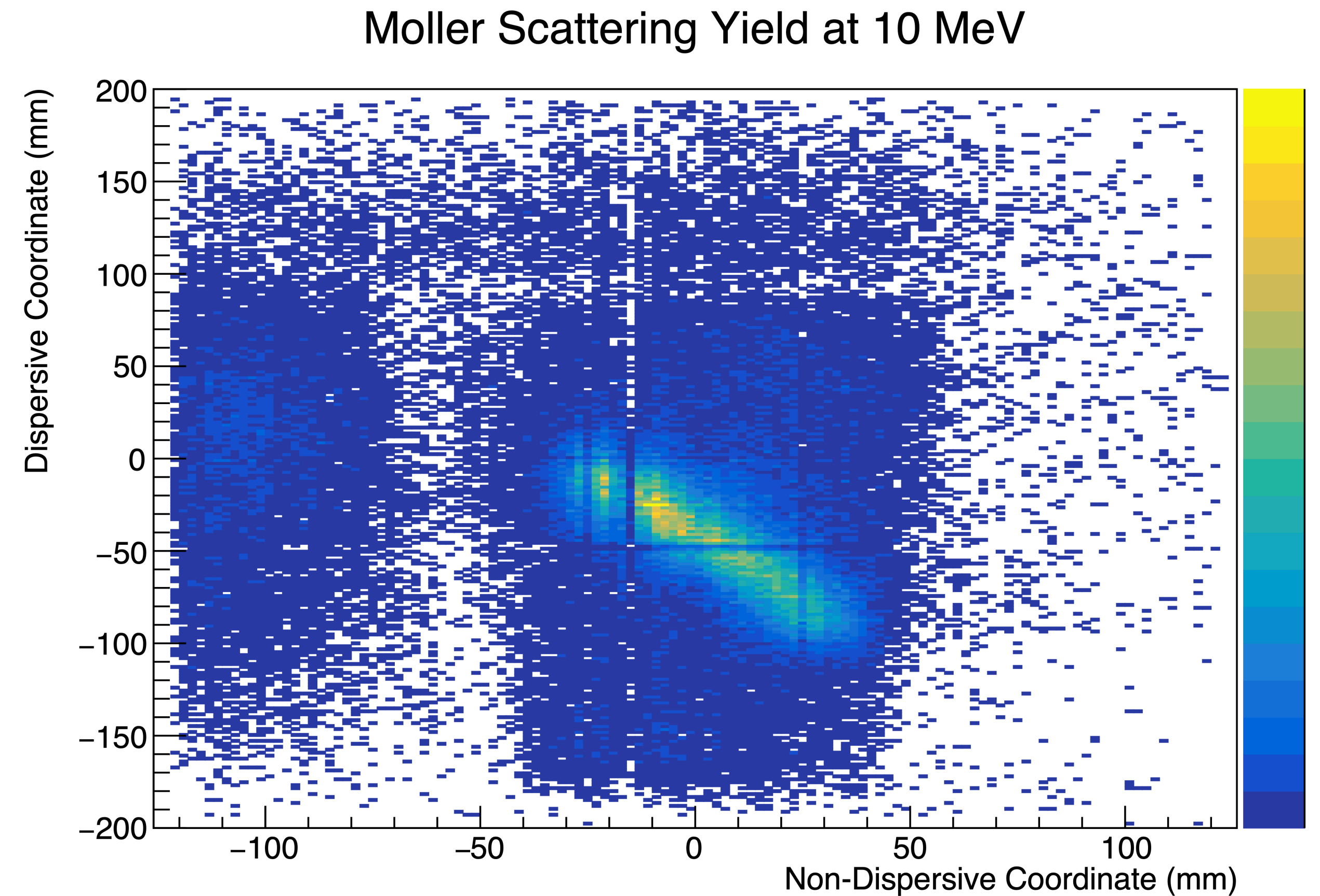
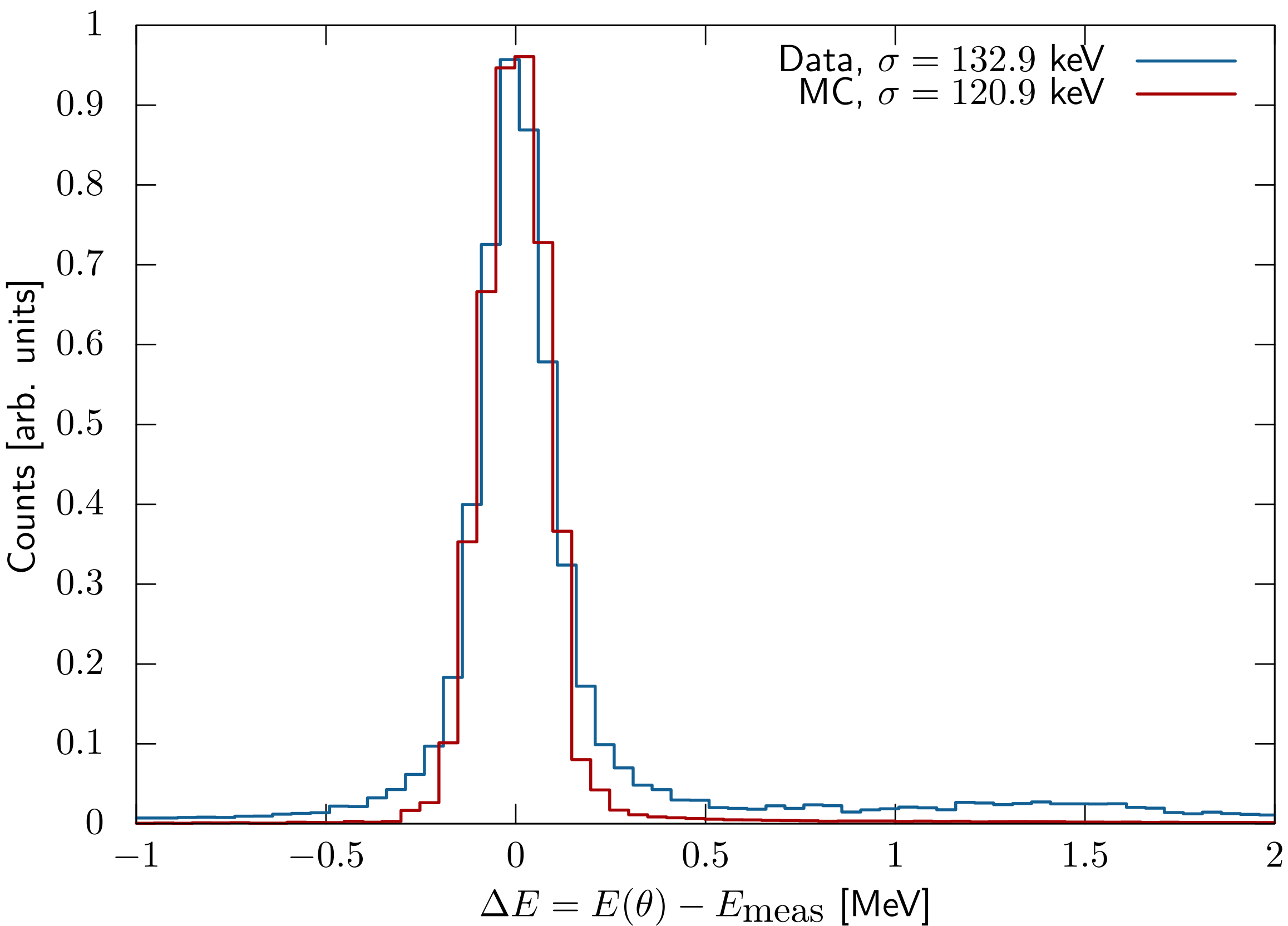
16



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- GEMs are performing sub-optimally

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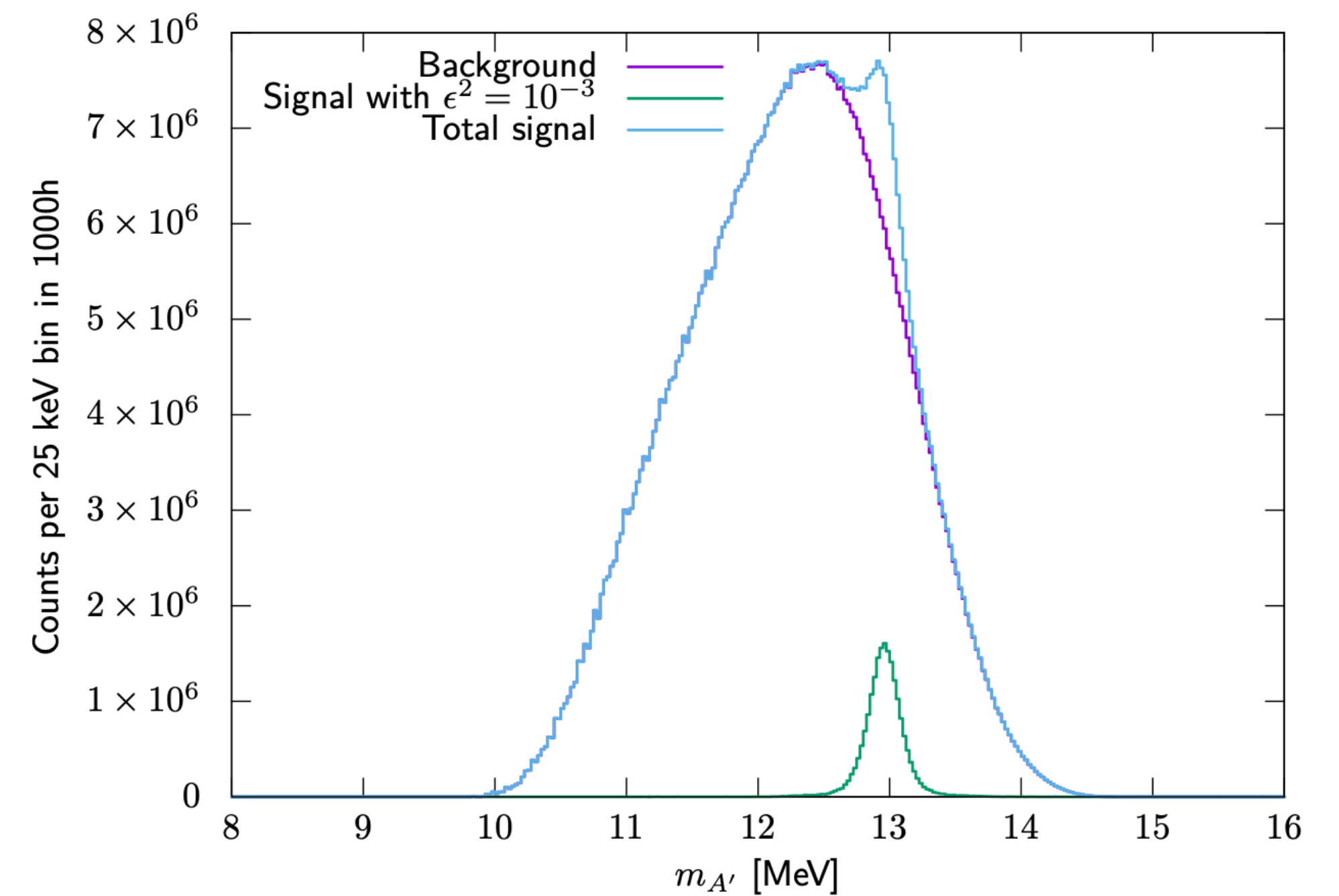


# Commissioning: Early 2026

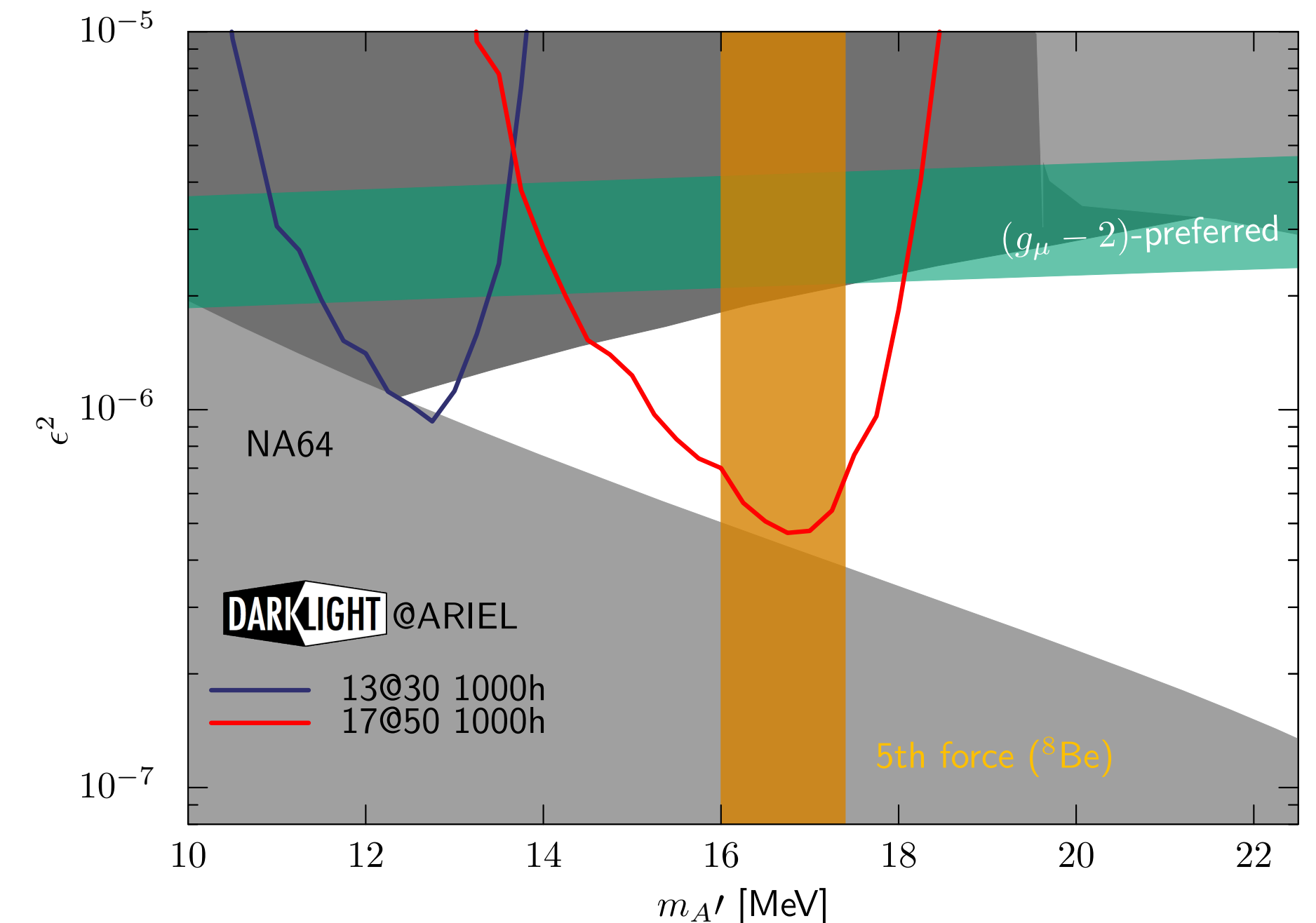
Goals	Success?
Ensure data acquisition system and detectors are functioning according to expectation	✓ (ish)
Measure the carbon elastic scattering peak and radiative tail	✓ (ish)
Measure inelastic carbon scattering	✗ (probably)
Measure radiative Moller scattering	✓
Measure coincidences	??

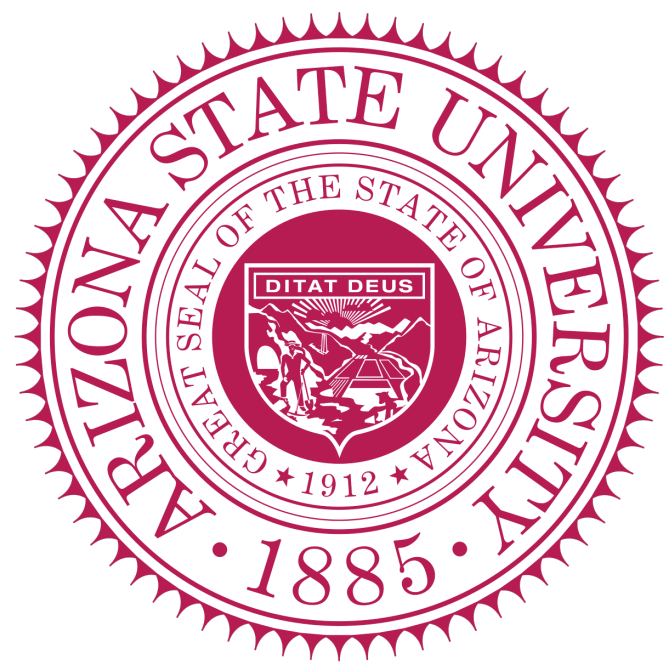
# Conclusions

- DarkLight was successfully installed and commissioned, finishing early 2026
- Papers documenting physics results from commissioning are currently in development
- Future plans:
  - Improving or upgrading the GEM detectors to improve reliability and results
  - Working with the eLinac team to better understand and reduce background
  - Additional data-taking in early 2027 at 30 MeV to build up coincidence statistics
  - Future run in early 2028 at upgraded 50 MeV eLinac energy



**Bump hunt!**





**Thanks for listening! Questions?**



# Backup

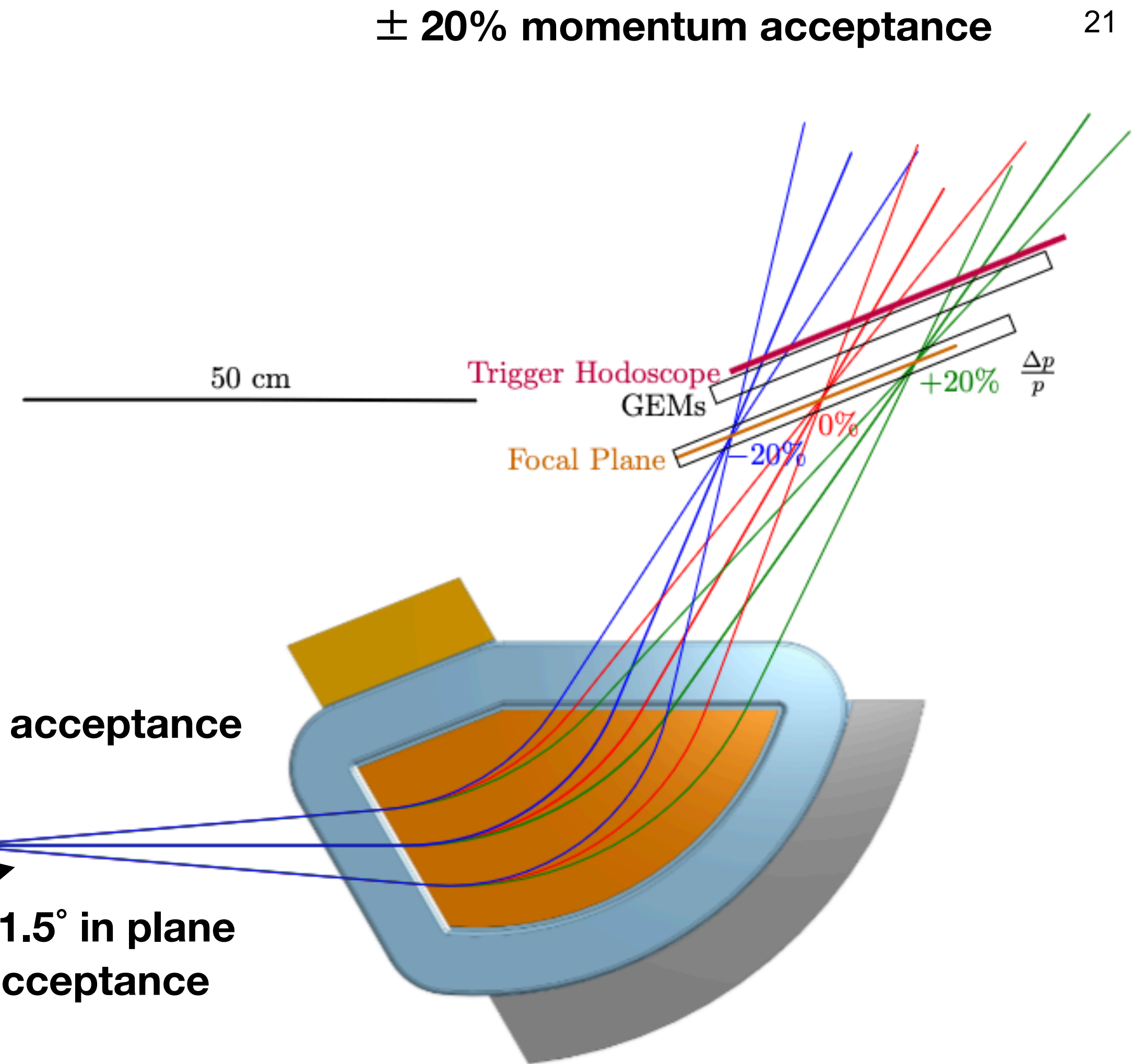
# Spectrometers

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



$\pm 5^\circ$  out of plane acceptance

$\pm 1.5^\circ$  in plane acceptance

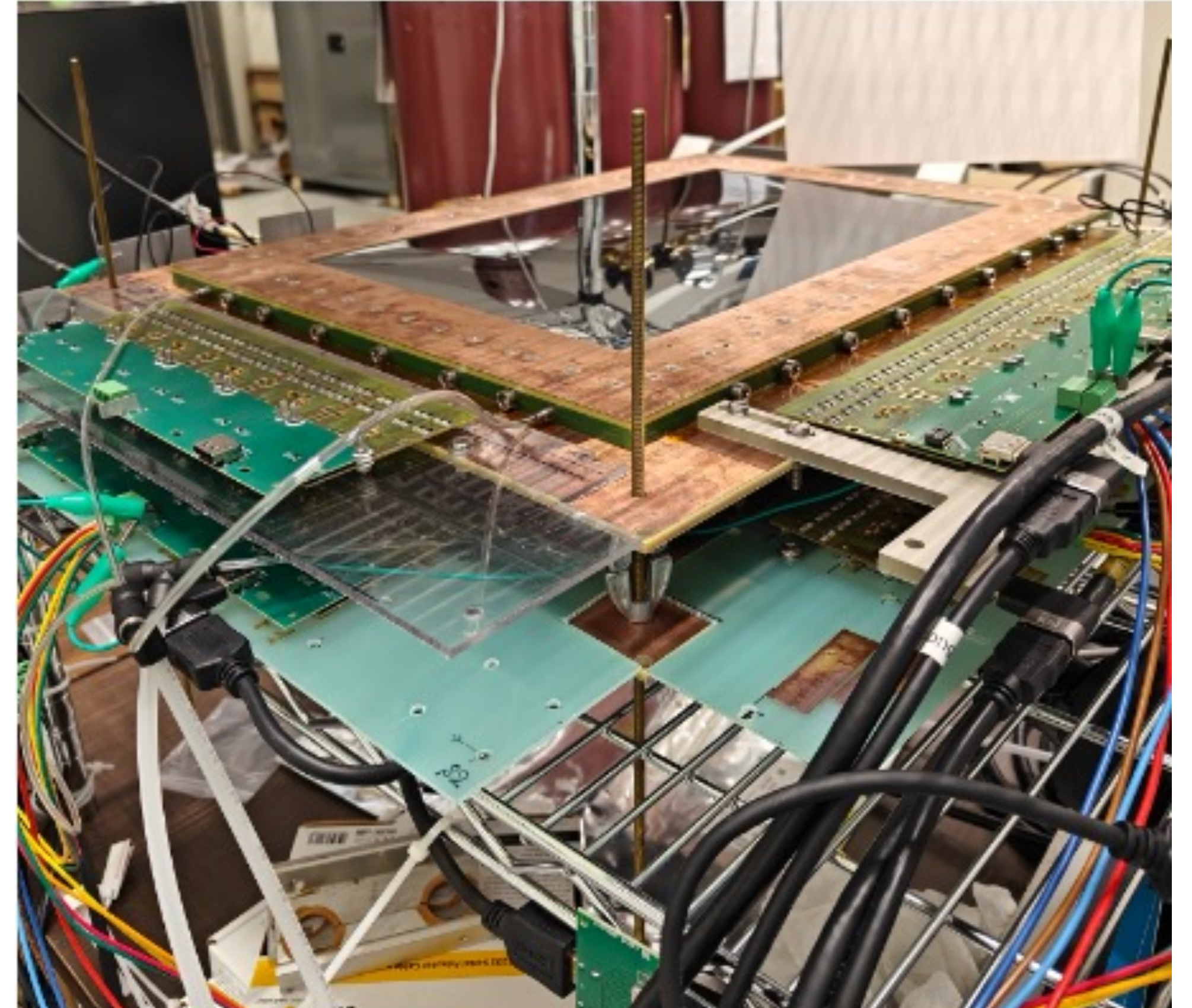
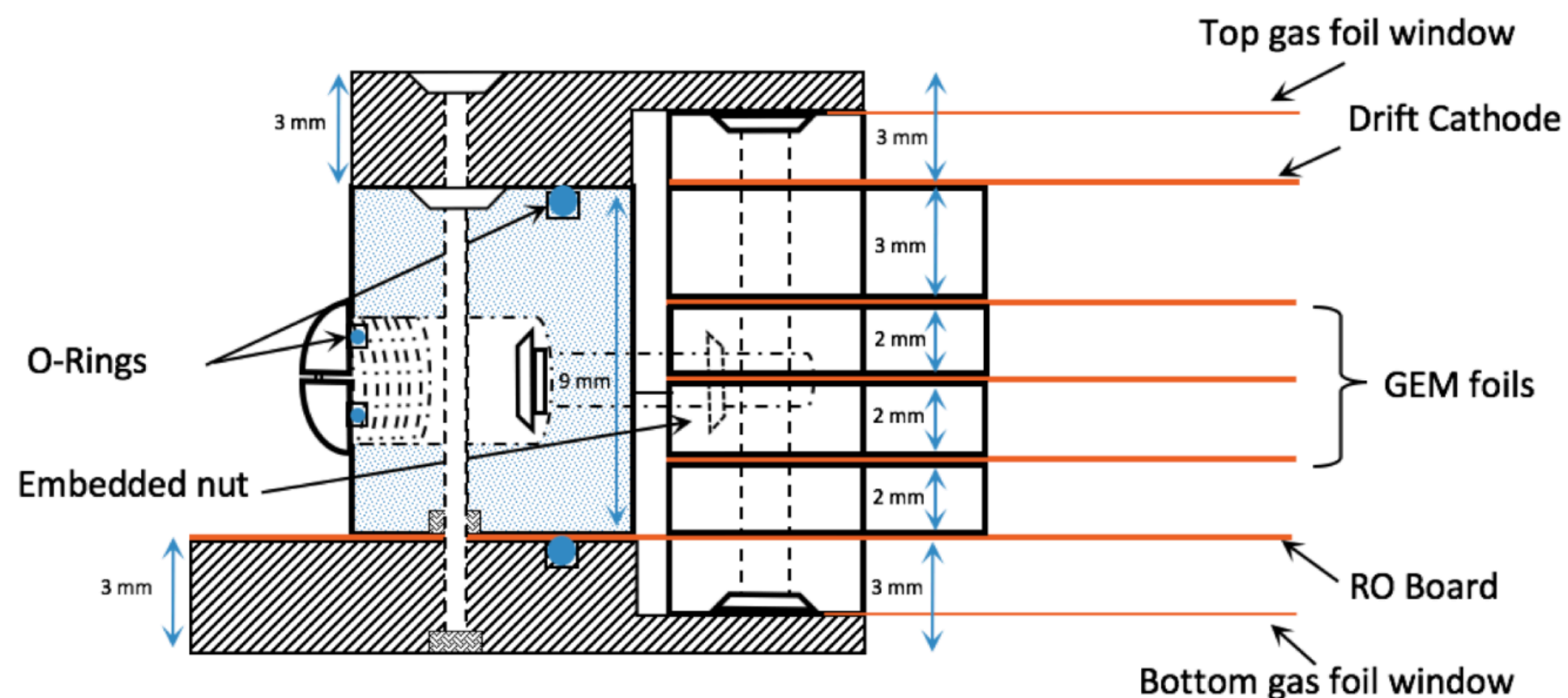


$\pm 20\%$  momentum acceptance

# GEMs

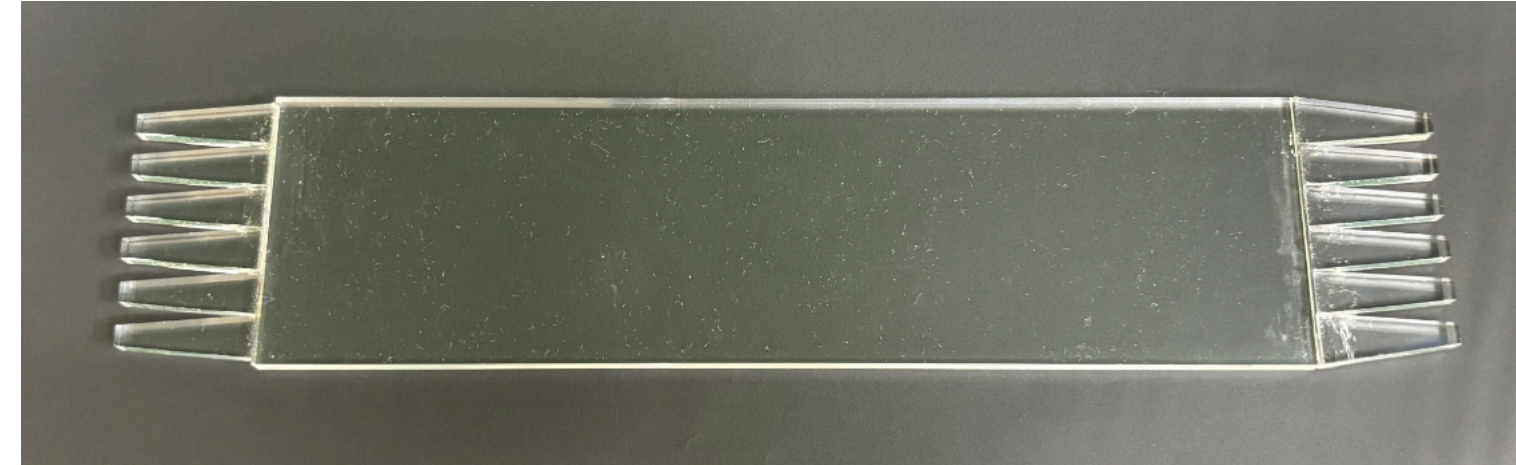
- **Gas Electron Multipliers**
- Tracking detectors to be used to reconstruct the 4 vectors for the electrons and positrons
- Preexisting 25 cm x 40 cm triple-GEMs built by Hampton University
- 400  $\mu\text{m}$  strip pitch
- APV cards with MPD4 readout
- Positional resolution of around 100 microns
- Readout time of around 200  $\mu\text{s}$

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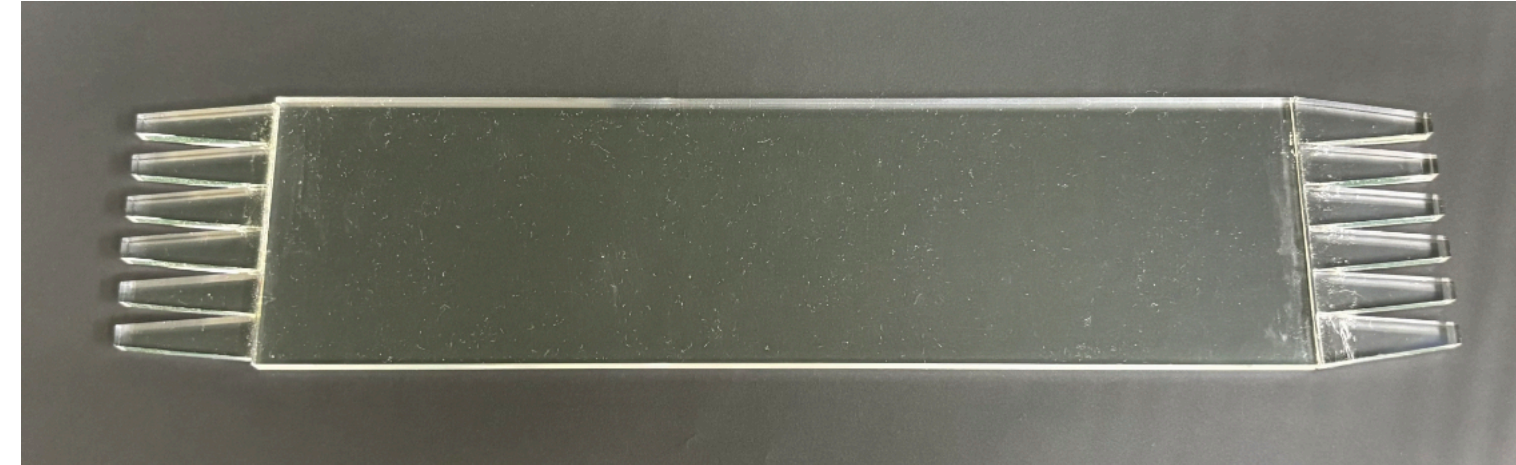
# Triggers

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



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- Readout boards contain 12 SiPMs each and accommodate two bars



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- 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

